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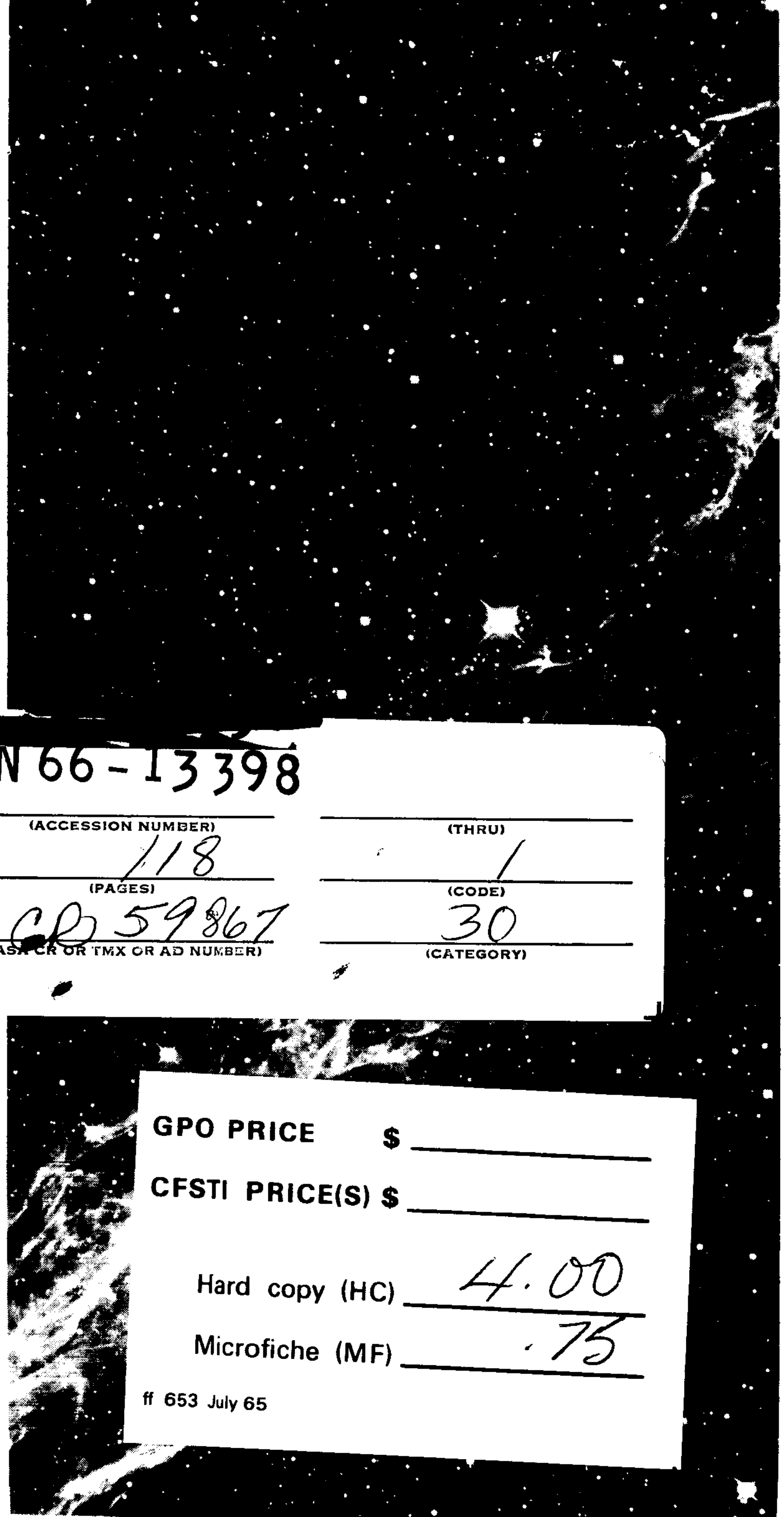

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Report No. T-7

PERTURBATION, SIGHTING AND TRAJECTORY ANALYSIS FOR PERIODIC COMETS: 1965-1975

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PERTURBATION, SIGHTING AND TRAJECTORY ANALYSIS FOR PERIODIC COMETS: 1965-1975

by

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ABSTRACT

PERTURBATION, SIGHTING AND TRAJECTORY ANALYSIS FOR PERIODIC COMETS: 1965-1975

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Possible intercept missions to the well known short period comets in the years 1965-1975 have been analyzed, to delineate those of potential interest in long range planning. A total of 36 well known comets having 55 perihelia in the period 1965 to 1975 were considered, plus Halley's comet with its perihelion in 1986. Detailed perturbation calculations were performed to determine the positions and perihelion dates of the 37 comets moving under the influence of gravitational fields of the Sun and planets. Ballistic trajectories to the comets were then calculated to determine ideal velocity, time of flight, closing velocity and communications distance as a function of launch date. Sighting calculations were performed to determine the expected brightness of the comets and the number of hours the comet might be visible in the night sky. ~~The 56 perihelia were then divided into three classes:~~

Author

Class I : Missions of Primary Interest
(6 perihelia plus Halley)

Class II : Missions of Secondary Interest
(10 perihelia)

Class III : Missions of Low Interest
(39 perihelia)

In order to be considered as either Class I or II a comet had to

1) Be recoverable two months before launch, that is, of brightness at least magnitude 20 and visible at least one to two hours per day from some latitude on Earth. (Magnitude 20 is an approximate lower limit for comet detection with current techniques).

2) Be visible at intercept (which is normally near perihelion).

3) Have an ideal velocity requirement ΔV of less than 53,000 ft/sec for a 30 day launch window, with a flight time of less than 400 days (53,000 ft/sec corresponds to a 400 pound payload on an Atlas Centaur vehicle with a solid fuel upper stage; it is sufficient for Jupiter missions).

The most important factor in eliminating missions from Class I or II is the sighting calculation, since most comets are not recoverable until months after their minimum energy launch windows. Of the 39 perihelia of low interest, 12 were placed there because of energy requirements alone and 27 were placed there because either the lateness of recovery forced the energy requirements above 53,000 ft/sec, or in a few cases, because the comets were not visible near perihelion. The division of the 17 Class I and II comets into 7 best and 10 secondary is clearly somewhat subjective, but based on trajectory and sighting data and on brief considerations of the scientific data available for each specific comet. With this last comment in mind, we may list the following seven "best" missions, in chronological order. The ΔV values are ideal velocities for 30 day launch windows.

Tempel 2 (1967)	Launch 4/67 with ΔV = 43,000 ft/sec. A bright comet at intercept (magnitude 10.5) for which some spectroscopic data is available. Easy early recovery, excellent sighting and easy trajectories make this most attractive mission in 1965-1975, although other comets are of greater scientific interest.
Schwassmann-Wachmann 2 (1967)	Launch 9/67 with ΔV = 46,250 ft/sec. An interesting dusty comet with excellent recovery and sighting, but rather faint (magnitude 15) at intercept.
Perrine-Mrkos (1968)	Launch 4/68 with ΔV = 45,400 ft/sec. Not a well known comet but bright (magnitude 8) at intercept.
Kopff (1970)	Launch 1/70 with ΔV = 41,900 ft/sec. Not a well known comet, but one with particularly low ΔV, although the flight time is long (10 months).
Pons-Winnecke (1970)	Launch 3/70 with ΔV = 45,100 ft/sec. A moderately bright (magnitude 13) comet at intercept, for which spectral data is available.
Encke (1974)	Launch 2/74 with ΔV = 47,700 ft/sec. A well known bright comet with short period (3.3 years); of high scientific interest. The very high closing velocity (35-40 km/sec) would complicate the mission; the short flight times and high closing velocities characteristic of Encke missions are also characteristic of missions to Halley's comet in 1986.
Halley (1986)	Launch 1/85 or 7/85 with $\Delta V \lesssim$ 43,000 ft/sec. The outstanding, bright, scientifically interesting comet, and a major goal for missions to the periodic comets. The very high closing velocity (2[illegible]-[illegible] km/sec) is the only possible problem. Recovery and sighting are outstanding, the flight times [illegible], and the energy requirement very low.

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PERTURBATION, SIGHTING AND TRAJECTORY ANALYSIS FOR PERIODIC COMETS: 1965-1975

1. INTRODUCTION AND GENERAL DISCUSSION

For long range planning purposes, it is of great interest to know which comets are accessible and attractive for exploratory missions in the next ten years. This report is the third in a series of five Astro Sciences Center reports on the comets; the first two were a discussion of the scientific objectives of missions to the comets (Roberts 1964a) and a compendium of data on periodic comets (Roberts 1964b); a fourth will discuss trajectories for 1975-1985 comets and new comets; a final report will discuss a few specific comet missions.

Since the comets are brightest and most active near perihelion, this study considered all short period comets which have well known orbits and which have perihelia in 1965 to 1975, plus Halley's comet which has its next perihelion in 1986. Table 5, page 13, shows the 37 comets considered and their 56 perihelion dates.

Because of (1) perturbing effects of the planets on comet orbits, (2) other accelerations in the comet motion and (3) inaccuracies in the comet orbital elements, the orbits of the comets are not well enough known to consider launching to a comet without first optically recovering and tracking the comet. In order to predict the future positions of the comets as accurately as possible detailed perturbation calculations must be carried out for each comet. The latest published data in the British Astronomical Association Handbooks (BAAH) or in Porter's Catalogue (Porter, 1961) were used as initial data for perturbation calculations. The Lewis Research Center NBODY code for the IBM 7090 computer was used to carry out the perturbation calculation; this code calculated the positions of the comets moving under the influence of the gravitational fields of the Sun and the planets Mercury through Uranus. To demonstrate the code's ability six NBODY perturbation calculations were checked with six published perturbation calculations, with close agreement.

Changes in perihelion time are the most important perturbation effects in trajectory studies. A comparison of the 48 comet perihelia in 1965 to 1975 as calculated from previous perihelia (STL, 1963) without perturbations with the same 48 perihelia calculated by including the perturbations showed an average change of 42 days in perihelion time. These perihelion time changes can severely affect trajectory calculations. For example, a 1966 launch to comet Grigg-Skjellerup requires an ideal velocity ΔV of 42,700 ft/sec. for a 30 day launch window. However, if perturbations are ignored the comet has a calculated perihelion date 52 days earlier, with a ΔV of 47,100 ft/sec. Thus the shift of

52 days in perihelion time changed trajectory energy requirements for Grigg-Skjellerup from a relatively high ΔV = 47,100 ft/sec to a low ΔV = 42,700 ft/sec.

The perturbation calculations also showed that some comets pass near Jupiter and that some make close approaches to Earth. Tables 1 and 2 detail these. Section 5 discusses the perturbation calculations in more detail. Appendix 1 contains osculating orbital elements for all the comets considered, through 1985.

Once the comet's orbital elements were determined by means of the perturbation calculation, the ASC/IITRI conic section trajectory system for the IBM 7090 (Pierce, Narin 1964) was used to calculate ballistic trajectories from Earth to each comet. The 30 day launch window which requires the minimum ideal velocity was determined for every comet of any interest. In addition to ideal velocity ΔV the codes determine communications distance RC, time of flight TF, closing velocity VHP and launch and arrival dates. Flight times of up to 400 days were considered. In order to be considered interesting a flight had to arrive at the comet within a few months of perihelion and have a ΔV requirement of less than 53,000 ft/sec. Of the 55 comet perihelia considered in 1965 to 1975 a total of 12 were rejected as not interesting because of these requirements alone. Section 6 discusses the trajectory calculations in more detail.

The last major stage in the computation was sighting calculations. Since most of the short period comets are relatively small and dim, the problems of detecting them are often formidable. The ground rules used in the study were that the comet should be visible 2 months before launch, at launch, and at intercept. By visible is meant approximately that the comet is above the horizon in the night sky for one to two hours from some latitude on Earth and at least as bright as magnitude 20. These computations were performed on the IBM 7090 using a specially written code SIGHT. Since the available data on comet brightness are very approximate some judgement was used in interpreting the calculated sighting date.

The most important effect of the sighting calculation is to raise the ΔV necessary to intercept a comet, because the first possible launch is assumed to occur two months after recovery (first sighting) of the comet. For example, the minimum energy 30 day launch window for comet Giacobini-Zinner starts on 10/24/71 with a ΔV of 41,800 ft/sec and a flight time of 290 days, arriving 6 days after perihelion. However, the comet will not be recoverable (magnitude $\sim$ 20) until the middle of January, 1972; the minimum energy launch window starting at 3/15/72 has a ΔV of $\sim$ 53,000 ft/sec. Thus the sighting constraint transforms Giacobini-Zinner from an easy 41,800 ft/sec Atlas-Agena class trajectory to one requiring 53,000 ft/sec, more than the energy required to go to

Jupiter.

Of the 44 comet perihelia left after elimination on purely trajectory grounds, the sighting requirements eliminated 27 and made many of the others much less interesting. Section 7 discusses the sighting calculations in more detail.

As a last step an attempt was made to choose from the trajectory data, the sighting data, and ASC/IITRI studies of the scientific interest of the comets (Roberts 1964a, 1964b) which comets are most attractive for exploratory missions. Fortunately, the scientifically interesting comets are the relatively bright and active comets which tend to be easy comets to intercept. However the final synthesis of trajectory, sighting and scientific data into an ordering of comet missions is a somewhat subjective procedure.

Before interpreting the data presented in the tables a number of points should be kept in mind; these points are discussed further in the other ASC/IITRI comet reports.

1) A most critical factor in intercepting a comet is the accuracy with which the comet orbital elements are known. A miss distance of 10,000 km would probably occur if the comet probe does not carry on-board comet acquisition and terminal guidance capability. Since comet nucleus diameters are typically 1-10 km, and comet diameters 20,000-2,000,000 km (Roberts 1964a) a probe without terminal acquisition and guidance will probably intersect the coma (if the comet has one) but not detect the nucleus at all.

2) It would be highly desirable to make spectroscopic measurements from Earth as the spacecraft intersects the comet. This implies the comet must be, approximately, magnitude 10 or 11 at intercept. Furthermore, since comet visibility is often just a few hours a day, and the spacecraft would typically be in the coma for only a few hours, timing the intercept so that the comet is visible could be a significant guidance problem.

3) The brightness of the comets is not well known, and changes from apparition to apparition; the brightness formulas are often in error by a few magnitudes. Thus all magnitude figures given are very approximate.

Table 1

COMETS WHICH APPROACH WITHIN 0.35 AU OF JUPITER

1964-1985

Comet	Date of Nearest Approach	Distance (AU)
D'Arrest	8/79	0.32
Grigg-Skjellerup	3/64	0.33
Harrington-Abell	4/13/74	0.083
Honda-Mrkos-Pajdusakova	3/27/83	0.113
Tuttle-Giacobini-Kresak	6/75	0.35

Table 2

COMETS WHICH APPROACH WITHIN 0.41 AU OF EARTH

1965-1975

Comet	Date of Nearest Approach ($\pm$ 3 days)	Distance (AU)
Encke	11/30/70	0.41
Encke	6/12/74	0.37
Honda-Mrkos-Pajdusakova	8/14/69	0.28
Honda-Mrkos-Pajdusakova	2/9/75	0.23
Perrine-Mrkos	11/14/68	0.33

2. SUMMARY OF RESULTS

2.1 Missions of Primary Interest (Chronological Summary Table)

Table 3 is a chronological summary table of the missions of primary interest. The first column gives the comet name and perihelion date. The second column gives the date at the beginning of the 30 day launch window; ΔV is the ideal velocity sufficient for launch anytime within this launch window, and TF is the time of flight range for the window. Note that the launch window is determined by sighting, as well as trajectory considerations. Normally the first flight takes the longest time; thus the launch on 3/30/67 for Tempel 2 has a flight time of 135 days, and arrives one day before perihelion. The arrival date of a flight launched at the beginning of the launch window is given in the third column; the spacecraft to comet closing velocity VHP is also given as is the Earth to comet communications distance RC at time of intercept.

The magnitude data given in the sighting data summary, columns 4 and 5, is very approximate and must be used as an indication of the brightness rather than as an exact figure. Column 4 gives the expected comet magnitude 60 days before launch, and the number of hours the comet would be above the horizon in the night sky for an observer at Earth latitudes + 25° and - 25°. Column 5 gives the corresponding data for the comet at intercept. The last column gives some general comments on the particular mission. The data used for the magnitude calculation is included in Section 7, Sighting Calculations.

Of the six missions in 1965-1975 the first, to Tempel 2, is very attractive since Tempel 2 is a bright comet of reasonable scientific interest, for which the recovery and sighting are excellent. It would probably be possible to recover Tempel 2 by 11/30/67, four months before launch; the extra two months of tracking, over the chosen minimum of two months, could greatly contribute to probable mission success.

Another attractive mission would be a shot to Encke in 1974. Encke brightens relatively rapidly as it approaches the Sun making early recovery difficult; however since Encke is very well known this would not be prohibitive. The required ΔV = 47,700 ft/sec for the short time of flight window is rather high, but by 1974 should not be any problem. The very high closing velocity, 35 to 38 km/sec, would be a serious problem, since this implies that a 100,000 km (coma) distance would be traversed in one hour or less. The high closing velocity also implies a high sensitivity to injection velocity errors. The similarity of Encke 1974 and Halley missions, especially in approach velocity, geometry of intercept and flight time is another reason for seriously considering Encke in 1974.

Of the other five comets in Table 3, Halley is, of course, of very special interest due to the wealth of data already available and Halley's extreme activity. Kopff is on the list because of the low energy requirement and not because of any special scientific interest. The other three are reasonably interesting scientifically and not unreasonably difficult shots.

2.2 Missions of Secondary Interest

Table 4 is a chronological summary table of missions of secondary interest; its form is identical to that of Table 3. Table 4 contains possible missions in which there is some interest, but not as much as in the missions of Table 3. All comets for which there are launch windows of TF $\leqq$ 400 days and $\Delta V \leqq$ 53,000 ft/sec (after accounting for recovery and sighting restrictions) are included in Table 4. Schwassmann-Wachmann 1, for which the flight time is 950 days, is included as a special case, since its perihelion distance of 5.4 AU rules out any lower energy, shorter flights. Because of its observed fluctuations in magnitude it is of considerable scientific interest.

2.3 All Missions (Alphabetical Summary Table)

Table 5 is a listing of all perihelia; if the ideal velocity requirements are greater than 53,000 ft/sec for TF $\leqq$ 400 days the mission interest is given as low; if not the mission interest is primary or secondary, and the mission described in Tables 3 or 4. The comment on the low interest missions state the first reason for eliminating the mission; for example, a mission eliminated because of ΔV requirements alone might or might not also have recovery problems.

Table 3

CHRONOLOGICAL SUMMARY TABLE OF MISSIONS OF PRIMARY INTEREST

Comet Name Perihelion Date	Trajectory Data Summary: Launch 1st Date, ΔV (30 day window), TF	Trajectory Data Summary: Intercept 1st Date, VHP, RC	Sighting Data Summary: Launch - 60 Days Magnitude, Visible Hrs at $\pm$ 25° latitude	Sighting Data Summary: Intercept Magnitude, Visible Hrs at $\pm$ 25° latitude	Scientific Data and General Comments
Tempel 2 8/13/67	3/30/67; ΔV = 43,000 ft/sec; TF = 110-135 days	1 day before perihelion; VHP = 11-12 km/sec; RC = 0.42 AU	Mag 18; visible 4 hrs at + 25°, 3 hrs at -25°	Mag 10.5; visible 7 hrs at + 25°, 10 hrs at -25°	A bright comet; early recovery, easy trajectories, excellent sighting; some spectroscopic data; probably the best mission in 1965-1975.
Schwassmann-Wachmann 2 3/13/68	9/18/67; ΔV = 46,250; TF = 245-265	88 days after; VHP = 7-9; RC = 2.5-3	Mag 17; Visible 2 hrs at $\pm$ 25°	Mag 15; visible 2 hrs at $\pm$ 25°	An interesting dusty comet, with excellent recovery and sighting; earlier intercept is possible at cost of ΔV.
Perrine-Mrkos 10/31/68	4/4/68; ΔV = 45,400; TF = 195-225	15 days after; VHP = 12-14; RC = 0.33	Mag 19; visible 0.3 hrs at + 25°, 0.2 hrs at -25°	Mag 8; visible 10 hrs at + 25°, 7 hrs at -25°	Not a well known comet; particularly bright at intercept; few weeks delay in recovery would not change the trajectory significantly
Kopff 10/6/70	12/22/69; ΔV = 41,900; TF = 285-315	27 days after; VHP = 9-10; RC = 1.8-2	Mag 19; visible 1.3 hrs at + 25°, 0.2 hrs at -25°	Mag 13; visible 2 hrs at + 25°, 2.5 hrs at -25°	Not a well known comet; a long, but very low energy flight; shorter flights are possible at higher ΔV's.
Pons-Winnecke 7/18/70	3/1/70; ΔV = 45,100; TF = 120-145	6 days after; VHP = 15; RC = 0.6-0.8	Mag 20; visible 5 hrs + 25°, 3 hrs at -25°	Mag 13; visible 3.5 hrs at +25°, 6 hrs at -25°	Spectroscopic data available; 30 day earlier launch would reduce ΔV by 2500 ft/sec
Encke 4/28/74	9/13/73; ΔV = 44,400; TF = 240-270; or 2/7/74; ΔV = 47,700; TF = 80-110	30 days after; VHP = 28; RC = 0.38; 43 days after; VHP = 35-38; RC = .40	Mag 22; visible 5 hrs at +25°, 6 hrs at -25°; Mag 18; visible 5 hrs at +25°, 3.5 hrs at -25°	Mag 9; visible 1 hr at +25°, 4 hrs at -25°; Mag 8; not visible at +25°, visible 2 hrs at -25°	A bright comet with short period (3.3 yrs) and perihelion distance; very interesting and well known, but difficult to see at perihelion; high VHP makes intercept mission difficult.
Halley 1/8/86	1/85; ΔV = 43,000; TF = 300; or 7/85; ΔV = 42,500; TF = 210;	50 days before; VHP = 26; RC = 0.5; 40 days after; VHP = 22; RC = 1.25	Mag$\sim$17; visible 10 hrs at +25°, 7 hrs at -25°; Mag$\sim$15; poor vis.	Mag$\sim$7; visible 7 hrs at +25°, 5 hrs at 25°; Mag$\sim$3; visible 2 hrs at +25°, 3 hrs at -25°	Outstanding, bright, interesting comet; recoverable 4 months before earliest launch; high VHP; a major goal for missions to periodic

Table 4

CHRONOLOGICAL SUMMARY TABLE OF MISSIONS OF SECONDARY INTEREST

	Trajectory Data Summary		Sighting Data Summary		
	Launch 1st Date, ΔV (30 day window) TF	Intercept 1st Date, VHP, RC	Launch - 60 Days Magnitude, Visible Hrs at $\pm 25°$ latitude	Intercept Magnitude, Visible Hrs at $\pm 25°$ latitude	Scientific Data and General Comments
Wolf-Harrington 2/14/65	6/20/64; ΔV = 42,500 ft/sec; TF = 200-230 days	9 days before perihelion; VHP = 12-13 km /sec; RC = 1.4 AU	Mag 21; visible 2 hrs at $\pm 25°$	Mag 15; visible 5 hrs at +25°, 3 hrs at -25°	Of historical interest only; fairly faint comet with no spectral data.
Wirtanen 12/15/67	8/14/67; ΔV = 45,300; TF = 145-165	42 days after; VHP = 10-11; RC = 1-1.1	Mag 20; visible 2 hrs at +25°, 4 hrs -25°	Mag 15; visible 7.5 hrs at +25°, 4.5 hrs at -25°	A faint, diffuse comet, rather poorly known.
D'Arrest 5/13/70	9/24/69; ΔV = 52,400; TF = 205-230	1 day before; VHP = 15-16; RC = 1.5	Mag 20; visible 2 hrs at +25°, 3 hrs at -25°	Mag 11.5; visible 1 hr at +25°, 2.5 hrs at -25°	A diffuse comet, not visible at launch; high energy requirement
Encke 1/9/71	6/30/70; ΔV = 45,900; TF = 110-140	53 days before; VHP = 29-30; RC = 0.43	Mag 22; visible 0.3 hrs at +25°, 0.7 hrs at -25°	Mag 11; visible 6.5 hrs at +25°, 4 hrs at -25°	Very marginal recovery; Encke is well enough known for recovery 30 days before launch.
Tempel 2 11/13/72	3/10/72; ΔV = 53,000; TF = 225-250	2 days after; VHP = 13-16; RC = 1.8-2	Mag 20; visible 4.5 hrs at +25°, 3 hrs at -25°	Mag 14; visible 2 hrs at +25°, 2.5 hrs at -25°	A relatively poor apparition of the comet.
Giacobini-Zinner 8/3/72	3/15/72; ΔV > 53,000; TF $\cong$ 150	9 days after; VHP $\sim$ 20 RC $\sim$ 1	Mag 20; visible 1.5 hrs at +25°, .5 hrs at -25°	Mag 11.5; visible 3 hrs +25°; 2.5 hrs -25°	An interesting, bright comet, but with very marginal recovery; 30 day less between recovery and launch reduces ΔV to 48,000 ft/sec.
Reinmuth 1 3/20/73	9/23/72; 46,800; TF = 195-205	27 days after; VHP = 9-12; RC = 1.7-2	Mag 20; visible 2 hrs at +25°, 2.5 hrs at -25°	Mag 16.5; visible 5 hrs at +25°, 4 hrs at -25°	A faint comet, not well known
Brooks 2 1/4/74	4/16/73; ΔV = 43,700; TF = 230-240	23 days before; VHP = 9-11; RC = 1.9-2	Mag 20; visible 1.5 hrs at $\pm 25°$	Mag 15.5; visible 3 hrs at +25°. 2 hrs at -25°	A faint comet, seen many times
Honda-Mrkos-Pajdusakova 12/31/74	10/26/74; ΔV = 46,900; TF = 75-100	34 days after; VHP = 24-27; RC = 0.23	Mag 20; visible 5.5 hrs at +25°, 6.5 hrs -25°	Mag 9.2; not visible +25°, visible 5 hrs at -25°	**A relatively bright apparition; not a well known comet.**
Schwassmann-Wachmann 1 1/30/74	2/3/71; ΔV = 51,900; TF = 920-950;	142 days before; VHP = 6-7; RC = 4.5-5	Observable every year Mag 18 at opposition, subject to fluctuations	Observable every year Mag 18 at opposition, subject to fluctuations	Perihelion of 5.4 AU makes this always difficult shot. Fluctuations in comet brightness are of interest.

Table 5

ALPHABETICAL SUMMARY TABLE OF ALL COMET PERIHELIA

Comet Name Perihelion Date	Mission Interest	Comments
Arend		
6/14/67	Low	Late recovery forces $\Delta V > 100,000$ ft/sec
5/26/75	Low	Late recovery forces $\Delta V > 90,000$ ft/sec
Arend-Rigaux		
4/1/71	Low	Late recovery forces $\Delta V > 53,000$ ft/sec
Ashbrook-Jackson		
3/1/71	Low	Not visible near perihelion
Borrelly		
6/17/67	Low	$\Delta V > 75,000$ ft/sec
5/11/74	Low	Late recovery forces $\Delta V > 60,000$ ft/sec
Brooks 2		
3/11/67	Low	Late recovery forces $\Delta V > 55,000$ ft/sec
1/4/74	Secondary	See Table 4
Comas-Sola		
10/30/69	Low	$\Delta V > 54,000$ ft/sec
Daniel		
5/31/71	Low	Late recovery forces $\Delta V > 75,000$ ft/sec
D'Arrest		
5/13/70	Secondary	See Table 4

Table 5 (Cont'd)

Comet Name Perihelion Date	Mission Interest	Comments
Encke		
9/21/67	Low	Late recovery forces $\Delta V > 65{,}000$ ft/sec
1/9/71	Secondary	See Table 4
4/28/74	Primary	See Table 3
Faye		
10/7/69	Low	$\Delta V > 53{,}000$ ft/sec
Finlay		
7/30/67	Low	Late recovery forces $\Delta V > 55{,}000$ ft/sec
7/8/74	Low	Late recovery forces $\Delta V > 55{,}000$ ft/sec
Forbes		
12/21/67	Low	Late recovery forces $\Delta V > 70{,}000$ ft/sec
5/19/67	Low	Late recovery forces $\Delta V > 55{,}000$ ft/sec
Giacobini-Zinner		
3/27/66	Low	$\Delta V > 70{,}000$ ft/sec
8/3/72	Secondary	See Table 4
Grigg-Skjellerup		
1/15/67	Low	Late recovery forces $\Delta V > 75{,}000$ ft/sec
3/1/72	Low	Late recovery forces $\Delta V > 65{,}000$ ft/sec
Halley		
1/[illegible]/86	Primary	See Table 3

Table 5 (Cont'd)

Comet Name Perihelion Date	Mission Interest	Comments
Harrington		
4/23/67	Low	Late recovery forces $\Delta V > 90,000$ ft/sec
2/17/74	Low	Late recovery forces $\Delta V > 100,000$ ft/sec
Harrington-Abell		
5/23/69	Low	Late recovery forces $\Delta V > 75,000$ ft/sec
Honda-Mrkos-Pajdusakova		
9/25/69	Low	Late recovery forces $\Delta V > 53,000$ ft/sec
12/31/74	Secondary	See Table 4
Johnson		
3/24/70	Low	Not visible near perihelion
Kopff		
10/6/70	Primary	See Table 3
Neujmin 1		
12/9/66	Low	Late recovery forces $\Delta V > 52,000$ ft/sec
Neujmin 3		
5/12/72	Low	$\Delta V > 52,000$ ft/sec
Perrine-Mrkos		
10/31/68	Primary	See Table 3
8/2/75	Low	$\Delta V > 60,000$ ft/sec
Pons-Winnecke 7/18/70	Primary	See Table 3

Table 5 (Cont'd)

Comet Name Perihelion Date	Mission Interest	Comments
Reinmuth 1		
8/6/65	Low	Late recovery forces $\Delta V > 53{,}000$ ft/sec
3/20/73	Secondary	See Table 4
Reinmuth 2		
8/18/67	Low	$\Delta V > 53{,}000$ ft/sec
5/8/74	Low	Not visible near launch or perihelion
Schaumasse		
7/3/68	Low	Late recovery forces $\Delta V > 55{,}000$ ft/sec
Schwassmann-Wachmann 1		
1/30/74	Secondary	See Table 4
Schwassmann-Wachmann 2		
3/31/68	Primary	See Table 3
9/10/74	Low	Not visible near recovery or perihelion
Tempel 2		
8/13/67	Primary	See Table 3
11/13/72	Secondary	See Table 4
Tuttle		
4/16/67	Low	Late recovery forces $\Delta V > 60{,}000$ ft/sec
Tuttle-Giacobini-Kresak		
11/12/67	Low	$\Delta V > 53{,}000$ ft/sec
6/7/73	Low	Late recovery forces $\Delta V > 54{,}000$ ft/sec

Table 5 (Cont'd)

Comet Name Perihelion Date	Mission Interest	Comments
Vaisala 1		
9/13/71	Low	Late recovery forces $\Delta V > 60{,}000$ ft/sec
Whipple		
10/10/70	Low	$\Delta V > 53{,}000$ ft/sec
Wirtanen		
12/15/67	Secondary	See Table 4
7/6/74	Low	$\Delta V > 55{,}000$ ft/sec
Wolf-Harrington		
2/14/65	Secondary	See Table 4
8/31/71	Low	$\Delta V > 65{,}000$ ft/sec
Wolf 1		
8/30/67	Low	$\Delta V > 60{,}000$ ft/sec

3. CONCLUSIONS

The first conclusion is that there do not seem to be any outstanding, easy missions to the well known periodic comets in the next ten years. Tempel 2, with a 1967 launch, is probably the most feasible mission; however, 1967 may be too early for serious consideration. The shot to Encke in 1974 is very interesting; the main problems for that mission would be the high closing velocity, and sighting. One very easy mission, to comet Kopff in 1970, is available; this comet might be useful for a first exploratory shot, as a prelude to other missions.

The second conclusion is that any analysis of comet missions must take careful account of perturbations and sighting; ignoring perturbation effects leads to completely erroneous trajectory data; recovery and sighting constraints are the strongest factor in differentiating possible from impractical missions.

A third conclusion is that, to interpret the trajectory and sighting data, careful consideration must be given to each comet on an individual basis; furthermore the possible scientific value of the missions can and should be a strong influence on the final assessment of any particular mission priority.

There are at least three possible extensions of this study which should be considered:

1) Extension to 1985
2) Inclusion of other periodic comets
3) Inclusion of new comets.

The first could be done directly with the sighting and trajectory computations, since the perturbation calculations have already been done to 1985. This would give a complete picture leading to a mission to Halley's comet in 1986.

The inclusion of other periodic comets is more difficult, since this study attempted to include all the well known comets; however, it is possible that there are a few other periodic comets, not as well known as the ones included in this study, which might be considered.

The possible inclusion of new comets is a somewhat different study. The new comets are particularly interesting in that they are often bright and active; however, since they cannot be predicted in advance any mission of that type implies a pre-built spacecraft and vehicle, on the shelf, waiting for discovery of the comet. It might be worthwhile, however, to survey the last few decades and ascertain if there would have been any very feasible missions of this type.

4. COMET ORBITAL ELEMENTS

The basic source of initial orbital elements was Porter's Catalogue (Porter 1961). Those comets listed by Porter which had perihelia for 1965 to 1975 were considered if, in general, the comet had been seen for at least two different perihelia. Wherever later elements were found in the BAAH, either from observations or perturbation calculations, these were used rather than Porter's elements. The epoch* of the starting date for the NBODY calculations were chosen to be the nearest even 50 Julian days to the published data. The source of initial elements for each comet, as well as the osculating elements themselves for the epoch of each perihelion, are shown in Table 6. The initial elements appear in Appendix 1 as the first line for each comet.

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* The epoch for a set of orbital elements is the day on which the elements are valid. Since the orbital elements for the comets usually change very slowly near perihelion it is valid to use the elements of the comets' orbit, for the epoch of perihelion, at any time within a hundred days of perihelion.

Table 6

COMET ORBITAL ELEMENTS FOR THE 1966-1975 PERIHELIA

Comet	Source of Initial Elements	Perihelion Year	a (AU)	e	i (deg)	Ω (deg)	$\overline{w}$ (deg)	T_p
Arend	Porter, 1961	1967	3.921	.535	21.67	357.53	42.16	1967/6/14
		1975	3.998	.538	19.97	355.68	42.58	1975/5/26
Arend-Rigaux	Christison and Gibbons, 1963	1971	3.601	.599	17.84	121.56	90.48	1971/4/[illegible]
Ashbrook-Jackson	Porter, 1961	1971	3.805	.400	12.52	2.17	350.99	1971/3/11
Borrelly	Porter, 1961	1967	3.658	.605	31.14	76.18	66.98	1967/6/17
		1974	3.576	.633	30.22	75.15	67.62	1974/5/11
Brooks 2	Porter, 1961	1967	3.561	.505	5.57	176.83	14.08	1967/3/11
		1974	3.616	.491	5.55	176.29	14.45	1974/1/4
Comas Sola	Porter, 1961	1969	4.182	.577	13.45	62.76	102.82	1969/10/30
Daniel	Marsden, 1963	1971	3.701	.549	20.11	68.49	79.51	1971/5/31
D'Arrest	Lea and Milbourn, 1963	1970	3.398	.652	17.01	141.77	320.13	1970/5/13
Encke	Makower, 1964	1967	2.217	.847	11.99	334.23	160.15	1967/9/21
		1971	2.217	.847	11.97	334.21	160.16	1971/1/9
		1974	2.217	.847	11.98	334.22	160.15	1974/4/28
Faye	Khanina, 1961	1969	3.800	.575	9.08	199.04	42.72	1969/10/7
Finlay	Porter, 1961	1967	3.627	.702	3.64	42.02	3.69	1967/7/30
		1974	3.645	.699	3.64	48.81	3.91	1974/7/8
Forbes	Beart, 1954	1967	3.451	.553	4.62	25.29	285.10	1967/12/21
		1974	3.445	.555	4.62	25.20	285.13	1974/5/19
Giacobini-Zinner	Porter, 1961	1966	3.450	.729	30.95	195.97	8.89	1966/3/27
		1972	3.489	.715	31.71	195.13	7.01	1972/8/3
Grigg-Skjellerup	Dinwoodie, 1962	1967	2.971	.663	21.04	212.72	211.83	1967/1/15
		1972	2.970	.663	21.05	212.69	211.91	1972/3/1
Harrington	Porter, 1961	1967	3.596	.559	8.68	119.08	352.02	1967/4/23
		1974	3.604	.557	8.66	119.01	351.97	1974/2/17
Harrington-Abell	Marsden, 1962	1969	3.732	.524	16.83	145.85	124.21	1969/3/23
Honda-Mrkos-Pajdusakova	Christison and Delo, 1964	1969	3.010	.814	13.17	233.10	57.26	1969/9/25
		1974	3.033	.809	13.14	232.98	57.55	1974/12/31
Johnson	Julian and Wheel, 1963	1970	3.578	.385	13.91	117.88	323.75	1970/3/24
Kopff	Egerton, Ainslie and Calway, 1963	1970	3.456	.547	4.73	120.45	283.17	1970/10/6

Table 6 (Cont'd)

Comet	Source of Initial Elements	Perihelion Year	a (AU)	e	i (deg)	Ω (deg)	$\overline{w}$ (deg)	T_p
Neujmin 1	Porter, 1961	1966	6.852	.775	15.03	347.18	334.00	1966/12/9
Neujmin 3	Egerton and Julian, 1962	1972	4.817	.590	3.89	150.27	297.21	1972/5/17
Perrine-Mrkos	Julian and Egerton, 1961	1968	3.561	.643	17.74	240.21	46.26	1968/10/31
		1975	3.582	.639	17.79	239.95	46.45	1975/8/2
Pons-Winnecke	Marsden, 1963	1970	3.426	.636	22.32	92.79	265.02	1970/7/18
Reinmuth 1	Porter, 1961	1965	3.867	.487	8.29	121.15	130.58	1965/8/6
		1973	3.876	.486	8.28	121.10	130.60	1973/3/20
Reinmuth 2	Porter, 1961	1967	3.566	.455	6.98	296.08	341.73	1967/8/18
		1974	3.566	.456	6.98	296.09	341.56	1974/5/8
Schaumasse	Porter, 1961	1968	4.066	.704	11.93	85.96	138.52	1968/7/3
Schwassmann-Wachmann 1	Porter, 1961	1974	6.131	.111	9.75	319.68	332.84	1974/1/30
Schwassmann-Wachmann 2	Porter, 1961	1968	3.486	.384	3.73	126.02	123.71	1968/3/13
		1974	3.484	.385	3.73	126.00	123.36	1974/9/10
Tempel 2	Marsden, 1961	1967	3.025	.548	12.48	119.27	310.22	1967/8/13
		1972	3.024	.549	12.48	119.27	310.12	1972/11/13
Tuttle	Dinwoodie, 1953	1967	5.747	.822	54.38	269.80	116.60	1967/4/16
Tuttle-Giacobini-Kresak	Kresak, 1956	1967	3.139	.634	13.63	165.27	203.86	1967/11/12
		1973	3.141	.634	13.61	165.17	203.93	1973/6/7
Vaisala 1	Porter, 1961	1971	5.031	.629	11.49	134.76	184.45	1971/9/13
Whipple	Dinwoodie and Marsden, 1962	1970	3.821	.351	10.24	188.39	18.20	1970/10/10
Wirtanen	Porter, 1961	1967	3.538	.544	13.40	86.41	70.00	1967/12/15
		1974	3.258	.614	12.30	83.58	75.31	1974/7/6
Wolf-Harrington	Lea and Milbourn, 1964	1965	3.495	.538	18.46	254.21	81.24	1965/2/14
		1971	3.501	.537	18.44	254.20	81.22	1971/8/31
Wolf 1	Porter, 1961	1967	4.142	.395	27.30	203.80	5.06	1967/8/30

5. PERTURBATION CALCULATIONS

The perturbation calculations were carried out in the following manner:

The initial orbital elements were processed by the BNBODY code to convert from the standard heliocentric ecliptic coordinate system into the heliocentric equatorial system, and to punch out the complete input for the Lewis NBODY code. Using this input data the comet motion was determined from the date of the orbital elements through 1985 with the NBODY code.

The NBODY code (Strack and Huff, 1963; Dobson, Huff and Zimmerman, 1962) as used in this study numerically integrates the equations of motion of the comet under the influences of the gravitational fields of the Sun and the planets Mercury through Uranus. The computations are done on the IBM 7090 computer using a fourth order Runge-Kutta integration method with variable step sizes. The coordinate system was equatorial, referenced to the equator and equinox of 1950.0. Integration variables used were the comet orbital elements. The planet positions were calculated using the elliptical elements for the planets given in Table 1 of the Strack and Huff report. The output of NBODY was modified to provide the osculating orbital elements for the comets in heliocentric ecliptic coordinates. Appendix 1 contains the computed osculating orbital elements for the comets considered, through to 1985.

As an example of the calculation results, Table 7 shows orbital elements from a perturbation calculation on the comet Harrington-Abell. Harrington-Abell passes within 0.083 AU of the planet Jupiter in April 14, 1974. This near approach to Jupiter results in a change of nearly 4 months in the perihelion time and large changes in other orbital parameters. Note that the change in perihelion time is gradual and extended over 5 or 6 years starting in 1970, while the change in the other orbital elements occur primarily between 2/74, 2 months before closest approach to Jupiter, and 9/74, 5 months after. During this period the perihelion time changes by 45 days while the period changes by 2.8 years, and the inclination by 8°. The comet passes through perihelion in 1976 and between 1976 and 1986 and the time of the next perihelion advances only 10 days.

The key point of the perturbation studies, from the point of view of comet mission analysis, is the change in the perihelion time as the comet traverses its orbit; if the comet were influenced by the gravitational field of the Sun alone the perihelia would occur periodically, being separated in time by the units of the (constant) period of the comet. However, due to the influence of the gravitational fields of the planets, all of the orbital elements are perturbed and continuously changing. The change in perihelion time is normally the parameter which most strongly affect the trajectory and sighting calculations. Table 8 illustrates the magnitudes of the changes in perihelion time. The perihelion dates in the STL report (STL, 1963) were calculated by adding increments of one period to the previously observed comet perihelion dates. These perihelion dates are compared in the table with the more accurate dates as calculated by the NBODY code. Only 1965 to 1975 dates from the STL report are included. The average difference in the 46 perihelia is 42 days. If perihelia beyond 1975 are considered the differences are even larger. Note that for some comets, such as Grigg-Skjellerup and Perrine-Mrkos, the propagation of an early change in period shows as an increasing error in perihelion time.

To check out the capabilities of the NBODY code for doing comet perturbation studies, the calculated, published post-perturbation elements for six comets were checked against NBODY calculated post-perturbation elements; Table 9 shows the excellent agreement obtained. The agreement should not be expected to be exact since the published work used different position data for the planets, and different integration procedures. Furthermore the initial data used for the published Arend-Rigaux calculations were not available.

The following comets were checked:

Arend-Rigaux
Daniel
Faye
Neujmin 3
Oterma

Perrine-Mrkos

Column 1 lists the initial data. Column 2 gives the NBODY calculated post-perturbation elements. A comparison of Columns 1 and 2 then shows the change in the elements through the perturbation. Column 3 gives the published post-perturbation elements. A comparison of Columns 2 and 3 indicates the agreement between the NBODY results and the published results.

Table 7

OSCULATING ORBITAL ELEMENTS FOR COMET HARRINGTON-ABELL

Epoch Calendar	Epoch Julian	a (AU)	e (AU)	i (deg.)	Ω (deg.)	w (deg.)	T (yrs)	R_p (AU)	T_p (next perihelion)	R (AU)
2/5/62	2437700.5	3.741	.523	16.81	145.91	338.29	7.237	1.79	3/1/62	1.80
8/23/62	2432900.5	3.741	.523	16.81	145.91	338.28	7.236	1.79	5/26/69	2.36
12/5/65	2439100.5	3.747	.524	16.83	145.86	338.24	7.223	1.78	5/23/69	5.69
3/19/69	2440300.5	3.732	.524	16.83	145.85	338.36	7.211	1.78	5/23/69	1.88
10/5/69	2440500.5	3.734	.524	16.83	145.85	338.37	7.215	1.78	8/10/76	2.15
5/28/71	2441100.5	3.728	.525	16.84	145.68	338.31	7.198	1.77	8/3/76	4.86
7/1/72	2441500.5	3.721	.527	16.90	145.51	338.28	7.178	1.76	7/27/76	5.61
8/5/73	2441900.5	3.706	.533	17.19	145.20	338.37	7.135	1.73	7/15/76	5.55
2/21/74	2442100.5	3.683	.561	18.59	145.01	337.94	7.067	1.616	6/5/76	5.22
4/12/74	2442150.5	4.010	.588	17.93	144.79	329.36	8.031	1.653	3/20/76	5.07
6/1/74	2442200.5	4.565	.5211	11.75	141.99	318.08	9.753	2.186	4/5/76	4.88
9/9/74	2442300.5	4.581	.499	10.76	140.77	317.64	9.806	2.297	4/19/76	4.48
12/18/74	2442400.5	4.567	.494	10.61	140.42	317.93	9.759	2.311	4/22/76	4.06
10/14/75	2442700.5	4.541	.490	10.55	140.13	318.36	9.676	2.315	4/23/76	2.74
11/17/76	2442900.5	4.535	.490	10.55	140.12	318.42	9.659	2.314	12/20/85	2.32

Table 8

COMPARISON OF STL (UNPERTURBED) AND PERTURBED PERIHELION DATES: 1965-1975 PERIHELIA

Comet	STL Perihelion Date	Perturbed Perihelion Date	Change in Perihelion Date
Arend	6/17/67 4/2/75	6/14/67 5/26/75	-3 +54
Arend-Rigaux	2/9/71	4/1/71	+51
Borrelly	6/20/67 6/28/74	6/17/67 5/11/74	-3 -48
Brooks 2	3/8/67 11/26/73	3/11/67 1/4/74	+3 +39
Comas Sola	11/4/69	10/30/69	-4
Daniel	8/18/70	5/31/71	+286
D'Arrest	7/11/70	5/13/70	-59
Encke	9/12/67 12/31/70 4/19/74	9/21/67 1/9/71 4/28/74	+9 +9 +9
Faye	12/29/69	10/7/69	-83
Finlay	7/25/67 6/17/74	7/30/67 7/8/74	+5 +21
Forbes	12/21/67 5/23/74	12/21/67 5/19/74	0 -4
Giacobini-Zinner	3/27/66 8/26/72	3/27/66 8/3/72	0 -23
Grigg-Skjellerup	11/24/66 10/19/71	1/15/67 3/1/72	+52 +134
Harrington	4/18/67 2/4/74	4/23/67 2/17/74	+5 +13
Honda-Mrkos-Pajdusakova	9/24/69 12/10/74	9/25/69 12/31/74	+1 +21

Table 8 (Cont'd)

Comet	STL Perihelion Date	Perturbed Perihelion Date	Change in Perihelion Date
Kopff	9/7/70	10/6/70	+29
Neujmin 1	12/5/66	12/9/66	+4
Perrine-Mrkos	9/2/68 2/19/75	10/31/68 8/2/75	+59 +164
Pons-Winnecke	7/9/70	7/18/70	+9
Reinmuth 1	11/7/65 7/14/73	8/6/65 3/20/73	-93 -116
Reinmuth 2	8/11/67 4/27/74	8/18/67 5/8/74	+7 +11
Schaumasse	6/22/68	7/3/68	+11
Schwassmann-Wachmann 2	3/18/68 9/29/74	3/13/68 9/10/74	-5 -19
Tempel 2	8/18/67 11/22/72	8/13/67 11/13/72	-5 -9
Tuttle	1/26/67	4/1[illegible]/67	+80
Tuttle-Giacobini-Kresak	10/19/67 4/13/73	9/2/67 4/16/73	-47 +3
Vaisala 1	10/25/70	9/13/71	+323
Wirtanen	12/15/67 8/16/74	12/15/67 7/6/74	0 -41
Wolf-Harrington	2/13/65 8/19/71	2/14/65 8/31/71	+1 +12

Average difference = 42 days

Table 9

NBODY PERTURBATION CHECK

COMET AREND-RIGAUX

Perturbing Bodies: Mercury, Venus, Earth, Mars, Jupiter, Saturn

	Initial Data[1]	NBODY Calculated Post-Perturbation Data	Published[2] Post-Perturbation Data
Epoch	9/8/57	9/16/63	9/18/63
w (deg)	326.40	328.88	328.86
Ω (deg)	124.65	121.66	121.61
i (deg)	17.20	17.85	17.85
q (AU)	1.385	1.436	1.437
e	.6107	.6008	.6002
a (AU)	3.559	3.597	3.594
T (yrs)	6.713	6.823	6.813
T_p	5/27/64	6/8.9/64	6/3.4/64

1 Porter, 1961
2 Christison and Gibbons, 1963

COMET DANIEL

Perturbing Bodies: Earth, Jupiter, Saturn

	Initial Data[1]	NBODY Calculated Post-Perturbation Data	Published[1] Post-Perturbation Data
Epoch	8/23/50	5/4/64	5/5/64
w (deg)	7.25	10.79	10.97
Ω (deg)	69.75	68.52	68.52
i (deg)	19.70	20.13	20.14
q (AU)	1.465	1.661	1.661
e	.5863	.5501	.5500
a (AU)	3.540	3.693	3.692
T (yrs)	6.662	7.093	7.094
T_p	12/25/63	4/21.8/64	4/21.7/64

1 Marsden, 1963

Table 9 (Cont'd)

COMET FAYE

Perturbing Bodies: Mercury through Uranus

	Initial Data[1]	NBODY Calculated Post-Perturbation Data	Published[2] Post-Perturbation Data
Epoch	8/3/47	5/17/62	5/16/62
w (deg)	200.53	203.78	203.56
Ω (deg)	206.35	198.95	199.12
i (deg)	10.53	9.07	9.09
q (AU)	1.66	1.61	1.61
e	.5637	.5757	.5757
a (AU)	3.812	3.791	3.790
T (yrs)	7.45	7.38	7.38
T_p	8/22/62	5/12.4/62	5/14.7/62

1 Bulletin of the Institute of Theoretical Astronomy of Leningrad 1959, Vol. VII N. 6 (89)

2 Khanina, 1961

COMET NEUJMIN 3

Perturbing Bodies: Venus, Earth, Jupiter, Saturn

	Initial Data[1]	NBODY Calculated Post-Perturbation Data	Published[2] Post-Perturbation Data
Epoch	5/28/51	12/7/61	12/7/61
w (deg)	144.81	147.68	147.65
Ω (deg)	156.20	150.61	150.68
i (deg)	3.76	3.86	3.86
q (AU)	2.032	1.969	1.970
e	.5880	.5913	.5910
a (AU)	4.931	4.816	4.817
T (yrs)	10.95	10.57	10.57
T_p	5/19/62	12/1.2/61	12/2.5/61

1 Julian, 1951, with a correction factor of -1.47 days to the date of perihelion

2 Egerton and Julian, 1962

Table 9 (Cont'd)

COMET OTERMA

Perturbing Bodies: Venus, Earth, Mars, Jupiter, Saturn

	Initial Data[1]	NBODY Calculated Post-Perturbation Data	Published[1] Post-Perturbation Data
Epoch	3/7/60	3/15/66	3/16/66
w (deg)	356.4	50.6	52.1
Ω (deg)	154.9	332.8	332.4
i (deg)	4.0	1.96	1.9
q (AU)	3.394	5.358	5.383
e	.147	0.249	0.250
a (AU)	3.978	7.17	7.18
T (yrs)	7.93	19.2	19.2
M (deg)	78.0	41.8	41.0

1 Marsden, 1961

COMET PERRINE-MRKOS

Perturbing Bodies: Jupiter, Saturn

	Initial Data[1]	NBODY Calculated Post-Perturbation Data	Published[2] Post-Perturbation Data
Epoch	9/30/55	3/17/62	2/25/62
w (deg)	167.78	165.93	165.95
Ω (deg)	242.56	240.28	240.27
i (deg)	15.88	17.74	17.74
q (AU)	1.154	1.268	------
e	.6675	.6434	.6435
a (AU)	3.471	3.557	3.556
T (yrs)	6.466	6.708	------
T_p	3/15.5/62	2/13.0/62	------

1 Prof. H. Hirose UAIC 1534

2 Julian and Egerton, 1961

6. TRAJECTORY CALCULATIONS

The first step in the trajectory analysis was to determine the minimum energy flights to the comets. For each comet a survey was run on the IBM 7090 computer of the parameters for Earth-to-comet one way ballistic flights. Times of flight of up to 400 days and launch dates from 500 days before perihelion until 100 days after perihelion were considered.

Figure 1, for example, is a plot of the minimum ideal velocity for flights to comet Encke vs. launch date, for the 1974 perihelion. Encke is a particularly complex case in that there are four different launch windows. However, the first two of these launch windows are eliminated from consideration because Encke is fainter than magnitude 20 until near the middle of the third launch window. Thus only the launch windows III and IV are of practical interest. (Since Encke is a very well known comet the requirement of 60 days between magnitude 20 and launch probably should be relaxed; as a result window III is not ruled out finally.)

Figure 2 is a plot of minimum ΔV and the corresponding TF, VHP and RC for the Encke launch window IV. From this figure the parameters for minimum energy launch on any day may be obtained. For example on 2/22/74 the minimum ideal velocity is 46,800 ft/sec; the 46,800 ft/sec launch has a flight time TF of 94 days, an Earth to Encke distance at intercept of 0.41 AU and a spacecraft to Encke closing velocity VHP of 35.0 km/sec.

For a 30 day launch window, beginning on 2/6/74, ΔV = 47,600 ft/sec, TF = 82-108 days, RC = 0.40 - 0.42 and VHP = 34-36 km/sec.

Table 10 is a summary table of the data for each of the four launch windows for Encke, and Table 11 is a summary of the 30 day launch window data for all of comets; however, it must be stressed that recovery problems make it impractical to launch during most of these windows. In Section 2, "Summary of Results", are listed the actual trajectory parameters required for launches to the comets, when the recovery and sighting restrictions have been accounted for.

The superscript "b" in the table indicates a launch window broken by the presence of a high energy spike corresponding to the transition between trajectories of flight angle HCA $<$ 180° (Type I) and HCA $>$ 180° (Type II). Figure 3 for the comet Honda-Mrkos-Pajdusakova is an example of such a broken launch window. The values of ΔV in the table are sufficient for 30 launch days surrounding the break; that is, if for two days the ΔV requirement is high during the launch window the ΔV in the table is for a 32 day wide window.

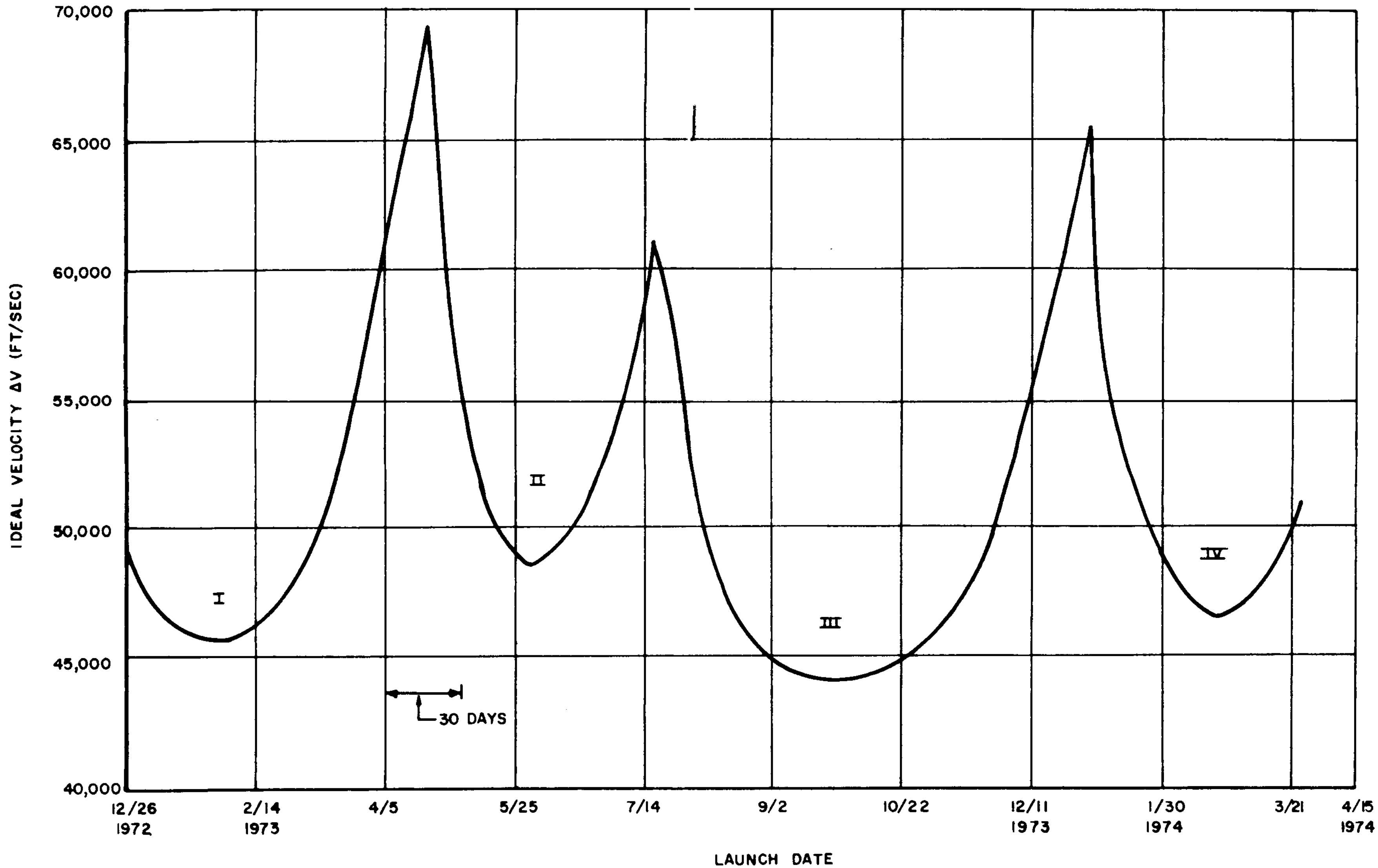

FIGURE 1

MINIMUM IDEAL VELOCITY FOR FLIGHTS TO COMET ENCKE: 1974 PERIHELION

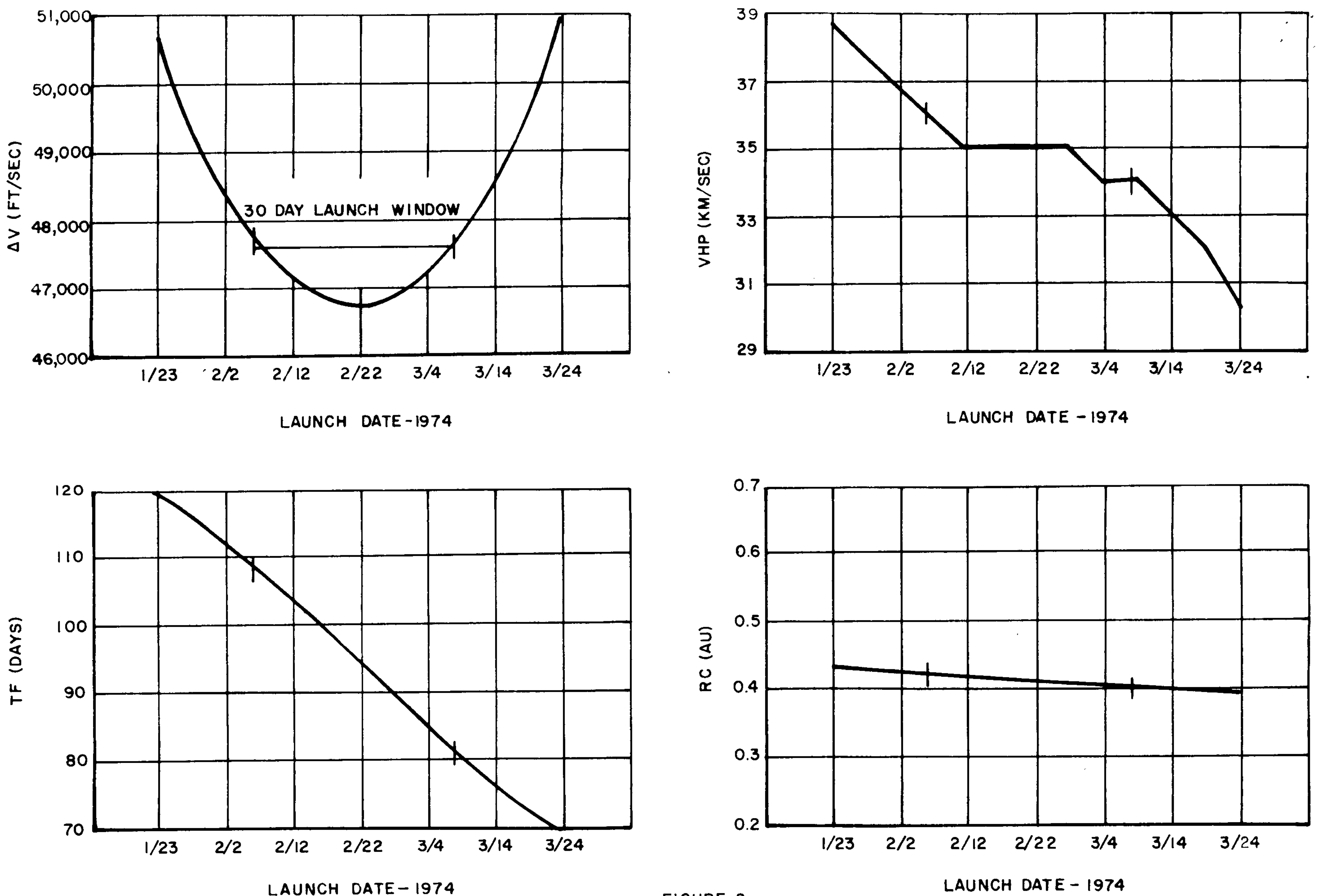

FIGURE 2

FLIGHT PARAMETERS FOR 1974 FLIGHTS TO ENCKE-LAUNCH WINDOW IV

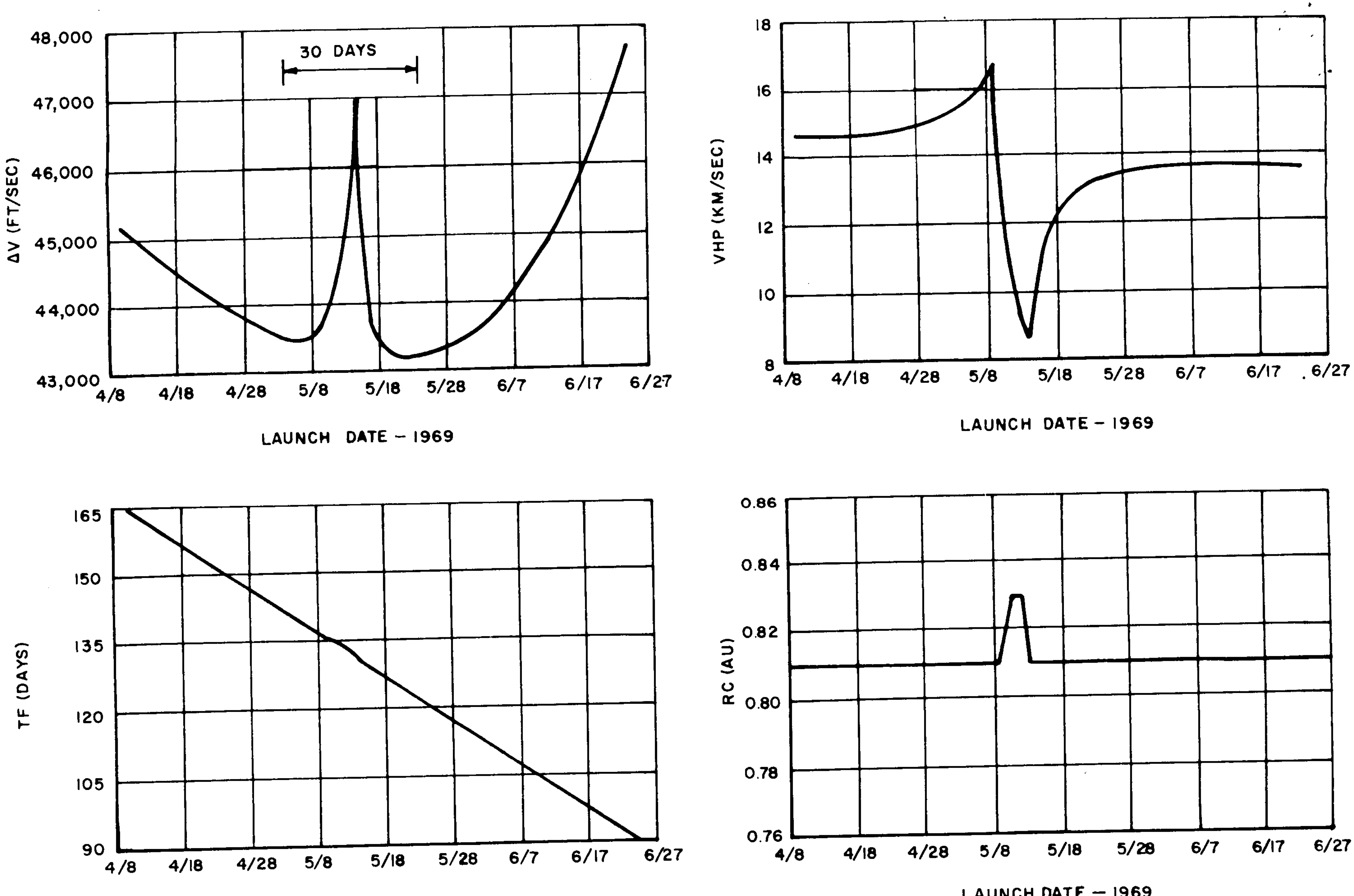

FIGURE 3

FLIGHT PARAMETERS FOR 1969 FLIGHTS TO HONDA-MRKOS-PAJDUSAKOVA

Table 10

FOUR LAUNCH WINDOWS TO COMET ENCKE IN 1973-1974

No.	First Launch Date	ΔV (for 30 day window, ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	First Arrival, Relative to Perihelion
I	1/14/73	46,200	380-415	22-23	1.9-2.0	34 days before
II	5/17/73	49,900	195-230	25-26	2.1	96 days before
III	9/13/73	44,400	240-270	28	0.38	43 days after
IV	2/6/74	47,600	82-108	34-36	0.40-0.42	31 days after

Table 11

MINIMUM ENERGY LAUNCH WINDOWS (WITHOUT CONSIDERATION OF SIGHTING CONSTRAINTS)

Comet Name Perihelion Date	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Beginning of Launch Window	First Flight Arrival (relative to perihelion)
Arend						
6/14/67	43,800[b]	345-375	12-13	3.0	3/1/66	95 days before
5/26/75	44,200[b]	310-340	13	2.9	3/9/74	103 days before
Arend-Rigaux						
4/1/71	42,000	310-335	13.7-14.2	2.1	6/12/70	42 days after
Ashbrook Jackson						
3/1/71	44,900	370-400	8.5-9.5	3.3	3/11/70	45 days after
Borrelly						
6/17/67	> 75,000	100-300	Of no interest			
5/11/74	42,100	405-430	18.7	2.3	3/12/73	5 days after
Brooks 2						
3/11/67	42,800[b]	320-345	8.7	2.6	2/23/66	36 days before
1/4/74	43,700	230-240	9.4-10.5	1.9-2	4/16/73	23 days before
Comas Sola						
10/30/69	> 54,000	100-300	Of no interest			
Daniel						
5/31/71	42,800	360-390	12	2.7	4/18/70	18 days before
D'Arrest						
5/13/70	52,400	205-230	15.5	1.5	9/24/69	1 day before
Encke						
9/21/67	46,650	180-210	38.5	1.3	1/25/67	29 days before
1/9/71	45,400	280-310	27.4-27.9	0.41	1/18/70	46 days before
1/9/71	45,900	110-140	29.1-29.8	0.43	6/30/70	53 days before
4/28/74	44,400	240-270	28	0.38	9/13/73	43 days after
4/28/74	47,600	82-108	34-36	0.40-0.42	2/6/74	31 days after

Table 11 (Cont'd)

Comet Name Perihelion Date	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Beginning of Launch Window	First Flight Arrival (relative to perihelion)
Faye						
10/7/69	> 53,000	100-400	Of no interest			
Finlay						
7/30/67	44,250	230-260	11.8	1.1	11/7/66	86 days after
7/8/74	46,900	220-240	12-13	1.34	11/2/73	
Forbes						
12/21/67	44,500	250-275	14-16	2.4-2.5	11/6/66	133 days before
5/19/74	51,400	Arrives year after perihelion - of no interest				
Giacobini-Zinner						
3/27/66	> 70,000	100-300	Of no interest			
8/3/72	41,800	260-290	22-23	.99	10/24/71	6 days after
Grigg-Skjellerup						
1/15/67	42,700	230-260	16-17	1.5	4/29/66	1 day before
3/1/72	40,900	260-290	14-16	.87	5/18/71	8 days after
Halley						
5/1/86	42,500	210	22	1.25	7/85	40 days after
Harrington						
4/23/67	43,200	365-405	8.9-9.6	2.8	12/15/65	89 days before
2/17/74	43,000[b]	280-310	11.6-12.3	2.4	1/10/73	94 days before
Harrington-Abell						
5/23/69	43,000[b]	315-340	11.1-11.5	2.7	7/25/68	13 days after
Honda-Mrkos-Pajdusakova						
9/25/69	43,750[b]	110-150	12-16	.81	4/28/69-6/4/69*	62 days after
12/31/74	46,900	75-100	24-27	.23	10/26/74	34 days after

* 38 day broken launch window with 8 day break

Table 11 (Cont'd)

Comet Name Perihelion Date	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Beginning of Launch Window	First Flight Arrival (relative to perihelion)
Johnson						
3/24/70	44,700	335-365	9-10	3.2	1/11/69	72 days before
Kopff						
10/6/70	41,900	285-315	9.2-9.8	1.8-2.0	12/22/69	27 days after
Neujmin 1						
12/9/66	41,700	305-320	13.2-13.7	2.1	2/10/66	18 days after
Neujmin 3						
~~5/17/72~~	> 52,000	100-400	Of no interest			
Perrine-Mrkos						
10/31/68	45,400	195-225	12-13.5	0.33	4/4/68	15 days after
8/2/75	> 60,000	100-400	Of no interest			
Pons-Winnecke						
7/18/70	40,800	180-210	14-16	0.63	12/28/69	8 days after
Reinmuth 1						
8/6/65	43,900	350-375	8.8-9	3.0	6/30/64	27 days before
3/20/73	46,800	195-205	9.5-11.5	1.7-2	9/23/72	27 days after
Reinmuth 2						
8/18/67	> 53,000	100-400	Of no interest			
5/8/74	44,300	355-390	8.9-9.3	3.1	12/30/72	104 days before
Schaumasse						
7/3/68	41,900	340-360	11.2-11.5	2.3	4/19/67	112 days before
Schwassmann-Wachmann 1						
1/30/74	51,900	920-950	6.8-7	4.5-5	2/3/71	142 days before
	54,300	600-700	8.5-11.5	5-6.5	3/5/72	4 days after
Schwassmann-Wachmann 2						
3/13/68	46,250	245-265	7.2-8.8	2.5-3	9/18/67	88 days after
9/10/74	44,500	420-430	7.9-8.2	2.9-3.1	6/26/73	23 days before

Table 11 (Cont'd)

Comet Name Perihelion Date	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Beginning of Launch Window	First Flight Arrival (relative to perihelion)
Tempel 2						
8/13/67	43,000	110-135	11.3-12	0.42	3/30/67	1 day before
11/13/72	41,300	315-340	10.1	1.8	11/23/71	16 days before
Tuttle						
4/16/67	41,000	370-400	31-33	1.5	2/19/66	21 days before
Tuttle-Giacobini-Kresak						
11/12/67	> 53,000	50-400	Of no interest			
6/17/73	40,750	245-275	12.5	1	7/28/72	49 days before
Vaisala						
9/13/71	45,000	260-280	14-16	2.7	8/23/70	106 days after
Whipple						
10/10/70	> 53,000	150-400	Of no interest			
Wirtanen						
12/15/67	45,300	145-165	10.1-10.7	1-1.1	8/14/67	42 days after
7/6/74	> 55,000	100-400	Of no interest			
Wolf-Harrington						
2/14/65	42,500	200-230	12.2-12.4	1.4	6/20/64	9 days before
8/31/71	> 65,000	100-300	Of no interest			
Wolf 1						
8/30/67	> 60,000	100-300	Of no interest			

7. SIGHTING

The general problem of optically recovering and tracking a comet is referred to as the "sighting" problem. Sighting is a major consideration in comet mission studies; for example, of the 56 comet perihelia considered in this study 27 were eliminated because of recovery or sighting problems.

Because of (1) perturbing effects of the planets, notably Jupiter, on comet orbits, and (2) other accelerations in the comet motion, and (3) inaccuracies in the comet orbital elements, comet orbits are not well enough known to permit considering launch to a comet without first optically recovering and tracking the comet. Perturbation calculations are usually sufficient to enable an observer to recover a comet; however, the precision of intercept required for a successful mission, typically 10,000 km miss distance, or less, requires a much more precise knowledge of the comet orbit.

After the comet has been recovered and tracked there is another critical sighting period, the time of probe encounter. Since one would wish to corroborate scientific experimental data from the spacecraft with visual observation, a daily period of viewing around intercept time is necessary. It would also be desirable for encounter to occur at a time of actual observation; if this is not possible then a period of viewing on the same day would probably be sufficient.

To determine in a quantitative manner the sighting characteristics of each comet perihelion, criterion were established that would realistically delineate those comets with easy or difficult sighting problems. At estimated recovery time it was required that the comet be of magnitude 20 or below (Roemer, 1961) since this is the upper working limit on most larger telescopes. The magnitudes were calculated from brightness equations derived from the British Astronomical Association Handbook. Based on empirical evidence from previous observation, the Handbook gives an equation for the magnitude M of the comet; typically, this equation is of the form $M = M_o + 15 \log r + 5 \log \Delta$, where M_o is a brightness number individual to each comet, r is the Sun-comet distance in AU, and Δ is the Earth-comet distance also in AU. This data, coupled with knowledge of previous apparitions, provides a method of estimating whether a comet will be bright enough for recovery.

The second criterion for recoverability was that of visible hours, that is, how many hours will a comet be above the horizon in the night sky; specifically excluded are daytime and twilight hours. There are two determining factors in the visible hours calculation.

1) How close to the Sun is the comet as seen from the Earth, that is, how close to conjunction is the comet?

2) From what Earth latitude is the observation being made?

The declination of the comet to the Earth's equatorial plane will determine the latitude which is most suited for observation; however the question remains of Sun interference with the sighting. This question is complicated since the duration of twilight varies greatly from latitude to latitude and from month to month. For instance at 50° N. latitude during the summer solstice twilight lasts all night so that even if the comet were circumpolar for that latitude it would still never be visible, unless it were very bright. Thus if the comet is in conjunction with the Sun it may come above the horizon only in the daylight hours, or a comet may be (angularly) far from the Sun, yet viewing at a given latitude may be prevented because of long twilight times.

It was estimated that one to two hours would be needed, exclusive of twilight, to complete a search for a comet at estimated recovery, and to photograph the image of the comet. This allows time for positioning the telescope, and the fact that observations within 15° of the horizon would introduce atmospheric distortion.

The problem of seeing the comet at intercept is somewhat similar; however, the faintness of magnitude 20 is not a restriction here because intercept occurs near perihelion when the comet is relatively bright. Thus at intercept the question is whether there will be sufficient night time observation at a particular latitude.

The preceding problem was coded in Fortran II as the SIGHT program for the IBM 7090 computer; SIGHT computes, for a range of latitudes on Earth, the number of hours per day that an object will be above the horizon in the night sky. From this information, and a knowledge of the peculiarities of each comet, it was estimated when each comet could be recovered and how visible the comet would be at intercept.

The interplay between the sighting question and the energy requirements for a mission is of the greatest interest. It was assumed that a two month period is necessary between recovery and first possible launch, to allow for tracking and launch pad operations; for many comets the combinations of late recovery and two months delay will make missions with any current vehicle out of the question. In any case, recovery criteria were responsible for the majority of the comets that were removed from further consideration.

In the tables listed in Section 2 sighting data for the primary and secondary interest missions are listed. The visible hours specify what viewing time will be at middle latitudes ($\pm$ 25°); in general if there is an advantage to be gained by observing in the northern or southern hemisphere it will show up here. In that table only the latitudes $\pm$ 25° are given but in the study a range of latitude from $\pm$ 50° were examined.

Consider an example that typifies the problems encountered in this area. To this example, comet Encke on its 1971 passage, the sighting criteria will be applied exactly to give an idea of the problems encountered and their ramifications. In actual fact the use of criteria were tempered somewhat by individual comet peculiarities. For instance, since Encke has a well known orbit, a full two months might not be required for observation, that is, its orbit might be sufficiently determined in only a month or less.

The minimum energy launch window for Encke's 1971 perihelion begins on 6/30/70, with a ΔV = 45,900 ft/sec. To determine if launch could occur on 6/30/70 consider the sighting conditions two months before 6/30/70. For Encke on 4/30/70 there are the following sighting parameters:

Magnitude = 22; Earth-Comet distance = 3.9 AU;

Comet-Sun distance = 3.1 AU;

Visible hours, + 25° = 0.26; Visible hours, - 25° = 0.77.

There is no advantage in other latitudes because - 25° latitude recorded the highest visible hours. We would conclude then from our criteria that Encke will not be seen because its magnitude is above 20 and there is not 2 hours viewing time.

On 6/26/70 however conditions have changed significantly. The sighting parameters then are:

Magnitude = 20; Earth-Comet distance = 2.9 AU

Comet-Sun distance = 2.7 AU

Visible hours, + 25° = 3.0; Visible hours - 25° = 3.8.

Encke at this time satisfies all recovery criteria so that launches on or after 8/26/70, two months after recovery, can now be considered. This will force a launch on non-minimum energy trajectories with a $\Delta V = 50,900$ ft/sec for a 30 day window starting in 8/26/70.

Figures 4 and 5 demonstrate the physical situation in this example. Figure 4 plots, on the ecliptic plane, the heliocentric longitude and radius of the Earth and comet Encke at various times. This figure ignores the out of plane component of Encke's orbit, and the tilt of the Earth's equator to the ecliptic, both of which affect the viewing from different latitudes; nevertheless, the figure presents a picture of the relative Earth-Sun-comet positions.

The first point on the graph 4/30/70 illustrates the conditions that we noted earlier. Encke at this time is rather far from both the Earth and the Sun; this raises the magnitude above 20 at this point. Also it is nearly in conjunction with the Sun which explains why the visible hours are few. At the second point 6/26/70 the situation has changed significantly. The Earth has moved to a position with close to four hours viewing per day, exclusive of twilight hours, and considerably closer to the comet, while Encke at the same time is moving closer to the Sun and brightening. This is the estimated first time of recovery.

Figure 5 is a graph of the minimum ΔV for all times of flight on the launch dates given. The minimum ΔV launch window begins 6/30/70. Note, however, the effect of waiting until 6/26/70 for favorable sighting. Adding two months for recovery and orbit determination yields 8/26/70 as the date of first possible launch; this is noted by the dotted line. At that time the ΔV then for a 30 day launch window is 50,900 ft/sec, 5,000 ft/sec higher than the minimum energy launch window; this fact severely limits this apparition as a possible mission.

Finally, Table 12 lists the parameters used in the brightness equation mentioned previously. For those comets for which no figures were available, previous apparitions were used to judge when sighting would first occur (Roberts, 1964b).

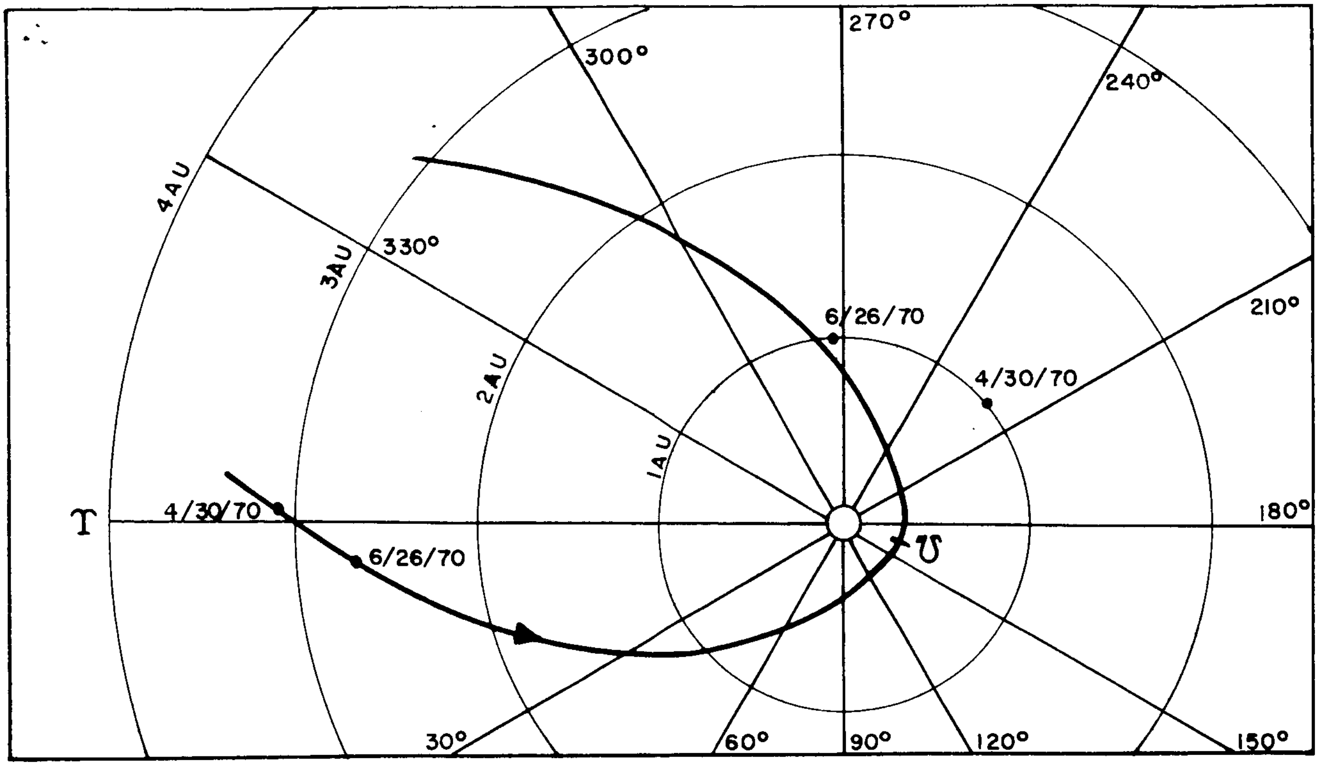

FIGURE 4

ORBITS OF THE EARTH AND COMET ENCKE PLOTTED ON ECLIPTIC PLANE

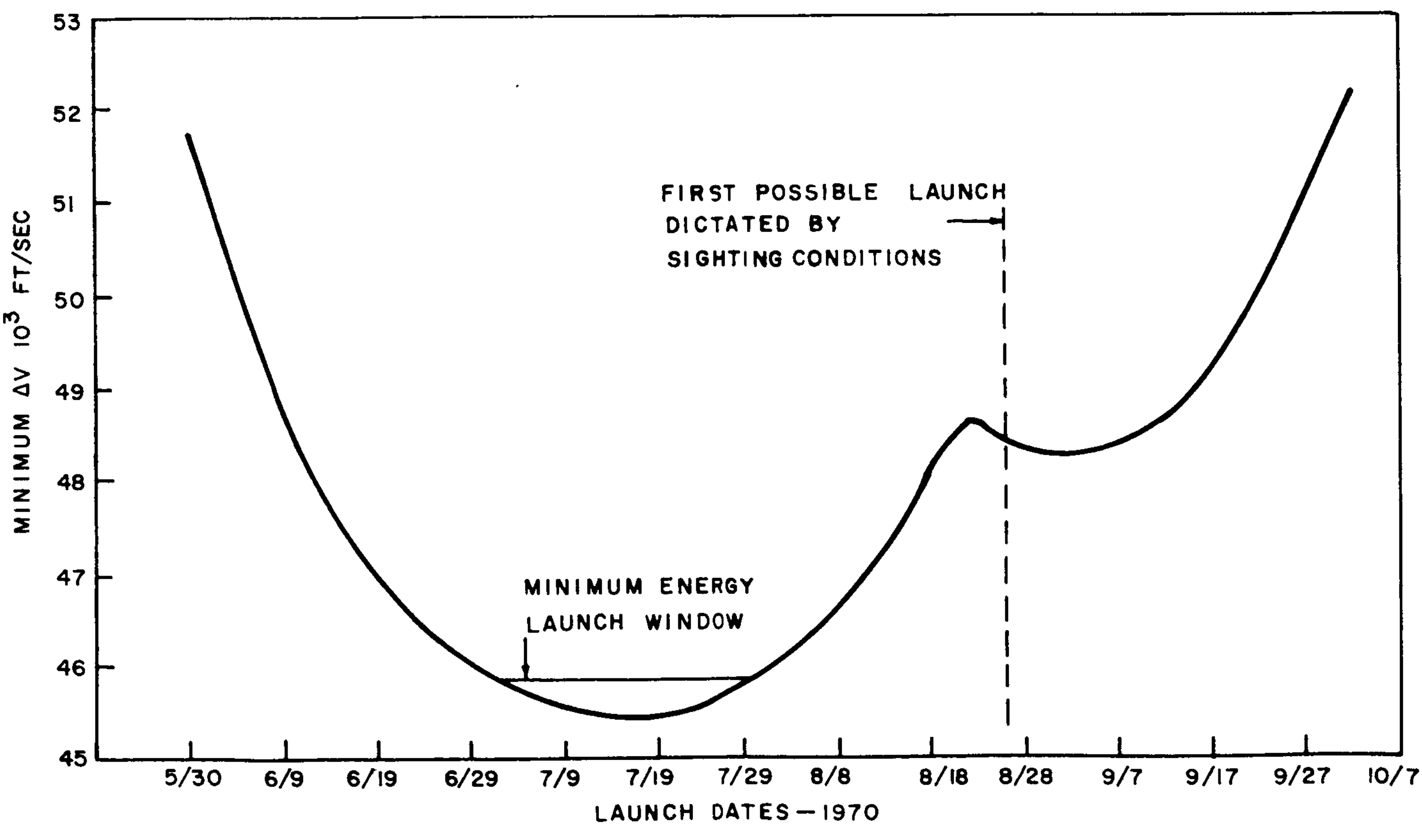

FIGURE 5

MINIMUM ΔV VERSUS LAUNCH DATE FOR FLIGHTS TO COMET ENCKE

Table 12

PARAMETERS USED IN THE MAGNITUDE EQUATION

$$M = M_o + A \log_{10} r + 5 \log_{10} \Delta$$

M = magnitude

M_o = individual comet brightness number

r = comet-Sun distance AU

Δ = Earth-comet distance AU

A,5 = empirical coefficients

A = 15 unless noted otherwise

Comet	M_o	Comet	M_o	Comet	M_o
Arend	11.5	Finlay	11.5	Pons-Winnecke	12.5
Arend-Rigaux	12	Forbes	11.3	Reinmuth 1	10.6
Ashbrook-Jackson*	11.5	Giacobini-Zinner	11.5	Schaumasse	10
Borrelly	10	Grigg-Skjellerup	13.4	Schwassmann-Wachmann 2	8.0
Brooks 2	10	Harrington-Abell	12	Tempel 2	10.5
Comas Sola	8.5	Honda-Mrkos-Pajdusakova	14.1	Tuttle	9.0
Daniel	11.5	Johnson	8.5	Tuttle-Giacobini Kresak	11.7
D'Arrest	9.5	Kopff	8.5	Whipple*	10.5
Encke	11.5	Neujmin 3	10	Wolf-Harrington	10.8
Faye*	11.1	Perrine-Mrkos	9.0		

* A in these cases equals 10

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APPENDIX 1

OSCULATING ORBITAL ELEMENTS TO 1985

This appendix consists of tables of the osculating orbital elements for the 37 short period comets considered in the study. The period covered is from the epoch of the published data through 1985. Points have been chosen to include a minimum of three points between comet perihelia. The computer runs, using the NBODY code, used a maximum time between data points of 200 days; however, when the elements are not changing rapidly, points have been omitted from the tables.

Figures A-1 and A-2 show the path Halley's comet would trace on a plane normal to the ecliptic plane and moving in longitude with the comet, that is, an accessible regions plot (Narin 1964) of the comet's heliocentric latitude and distance from the Sun.

Note how the 50 AU scale, Figure A-1, shows that the comet never approaches close to the outer planets, and spends most of its time below the ecliptic plane. Figure A-2 is the same diagram on a 5 AU scale, showing the perihelion portion of the comet orbit.

Tables A-1 through A-37 are the osculating orbital elements for the comets, in heliocentric, ecliptic coordinates relative to the equinox of 1950.0.

Figure A-3, A-4 and A-5 are included for reference. Figure A-3 shows the heliocentric, ecliptic coordinate system. Figure A-4 relates ΔV to VHL, and Figure A-5 relates ΔV to C_3.

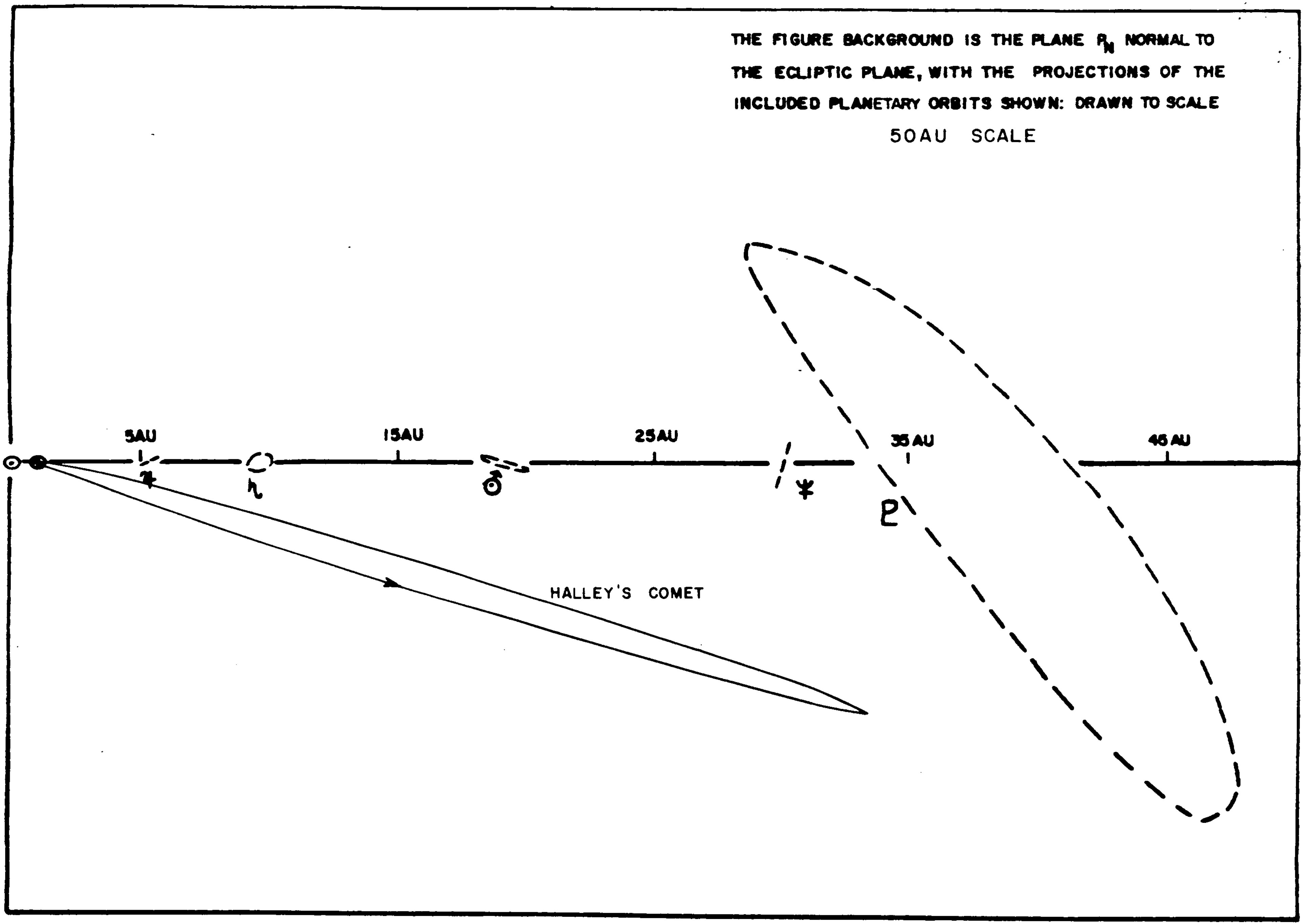

FIGURE A-1

THE ORBIT OF HALLEY'S COMET

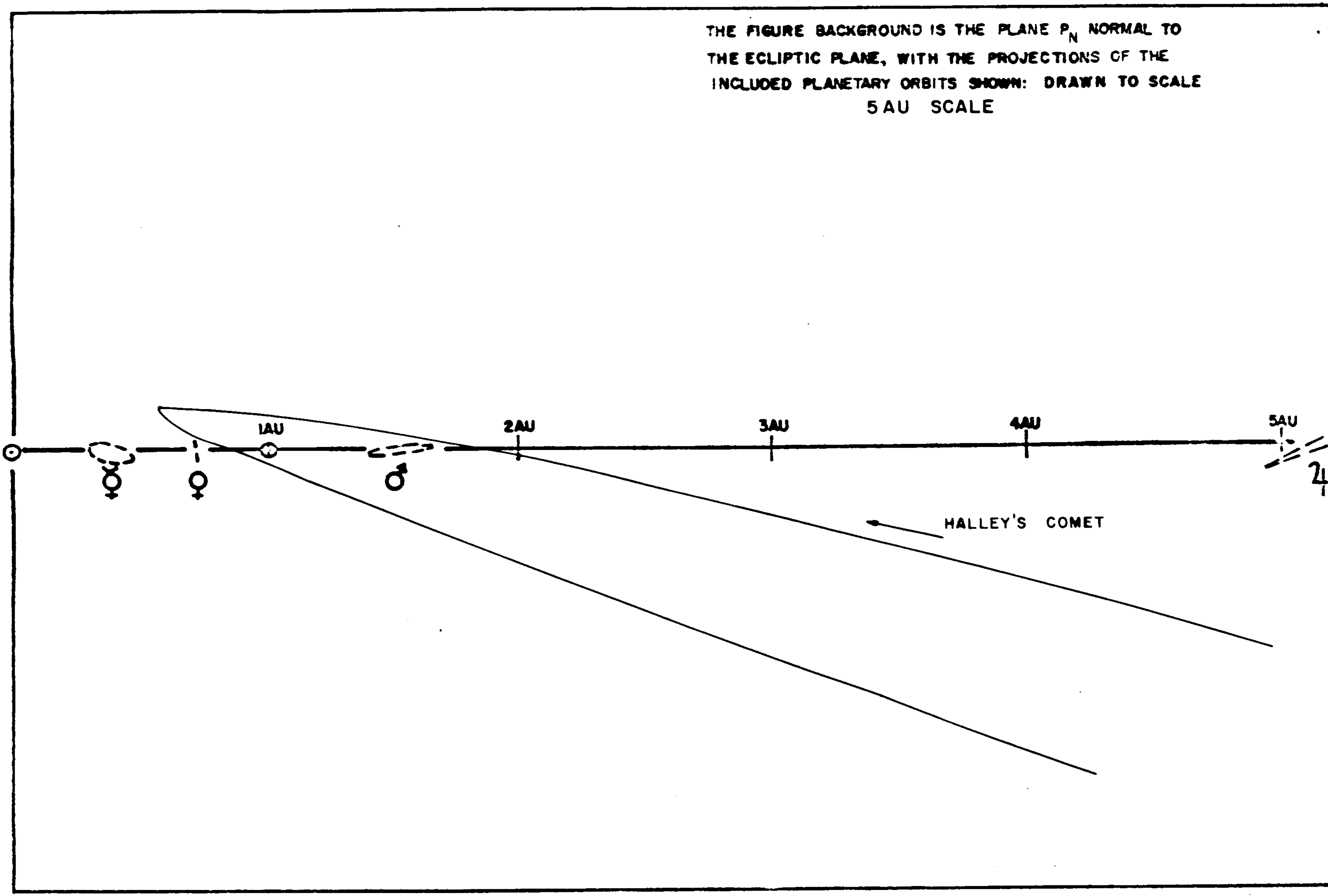

FIGURE A-2

THE ORBIT OF HALLEY'S COMET

Nomenclature

Ω = longitude of the ascending node
$\bar{\omega}$ = longitude of perihelion
ω = argument of perihelion
u = argument of latitude
η = true anomaly
β = heliocentric latitude
λ = heliocentric longitude
i = inclination

Useful Relations

$$\lambda = \Omega + \tan^{-1}(\cos i \;\tan u)$$
$$\sin \beta = \sin u \;\sin i$$

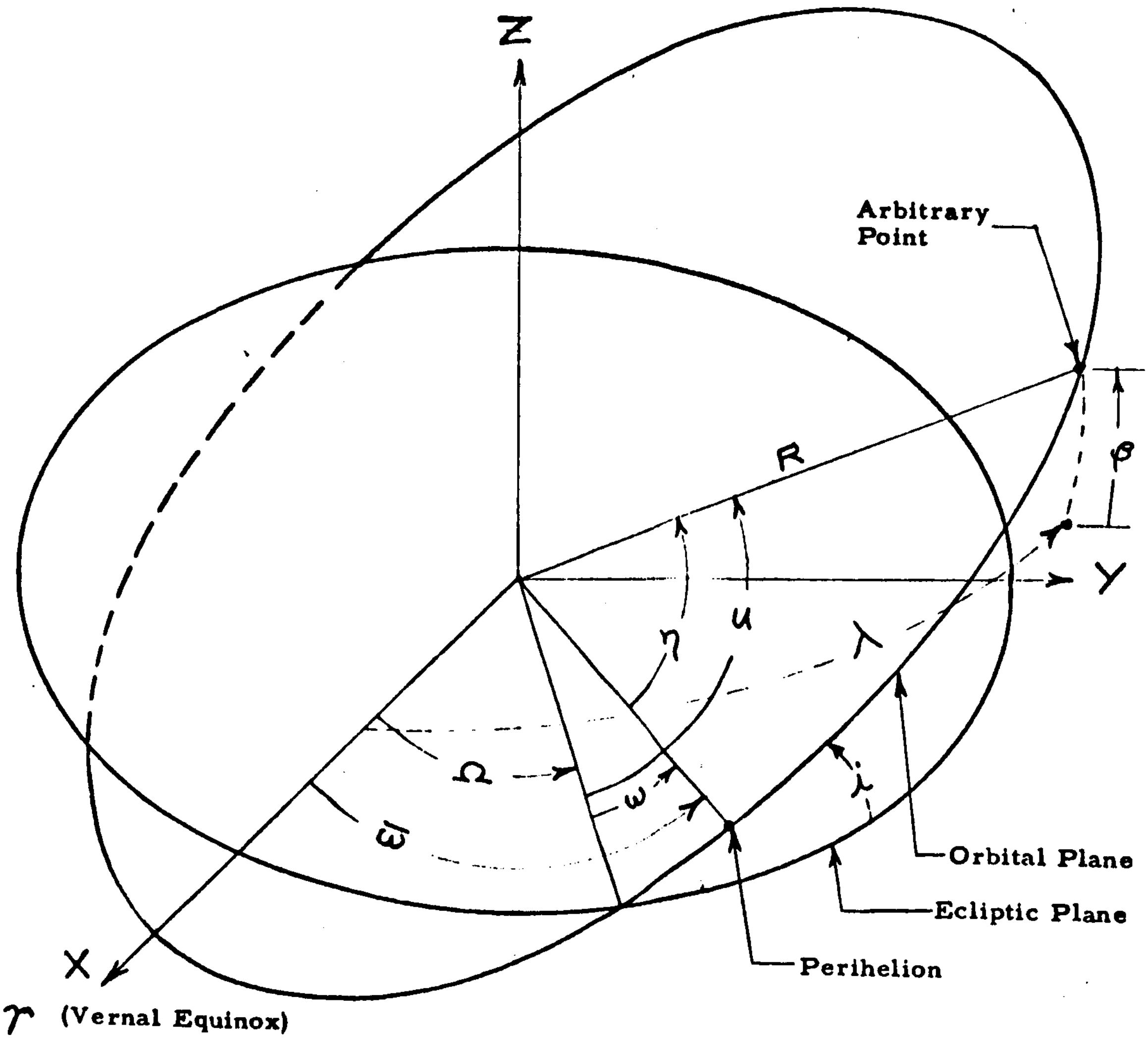

Figure A-3 HELIOCENTRIC, ECLIPTIC COORDINATE SYSTEM

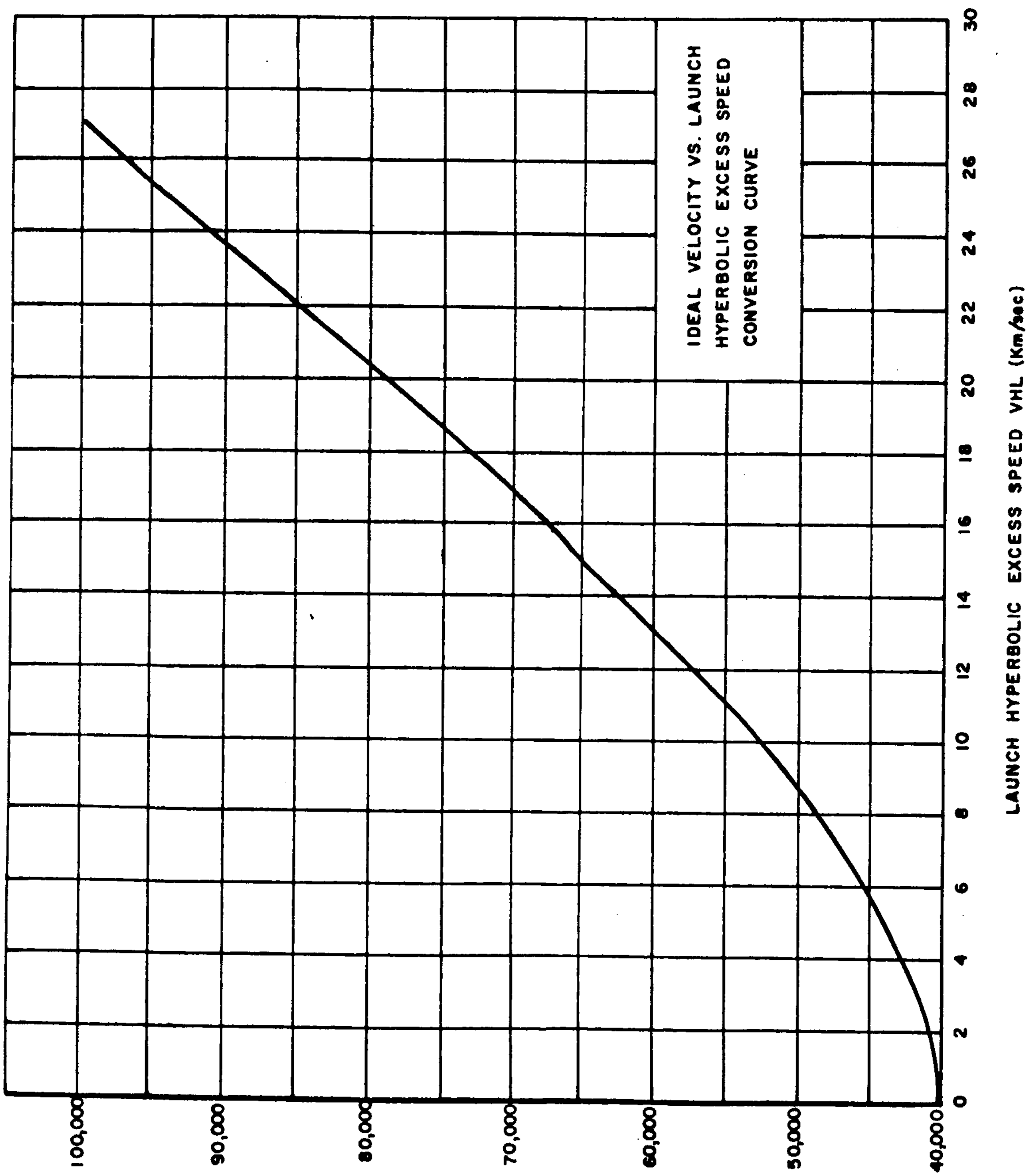
IDEAL VELOCITY VS. LAUNCH HYPERBOLIC EXCESS SPEED CONVERSION CURVE
LAUNCH HYPERBOLIC EXCESS SPEED VHL (Km/sec)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
IDEAL VELOCITY ΔV (Ft/sec)
40,000
50,000
60,000
70,000
80,000
90,000
100,000

Figure A-4

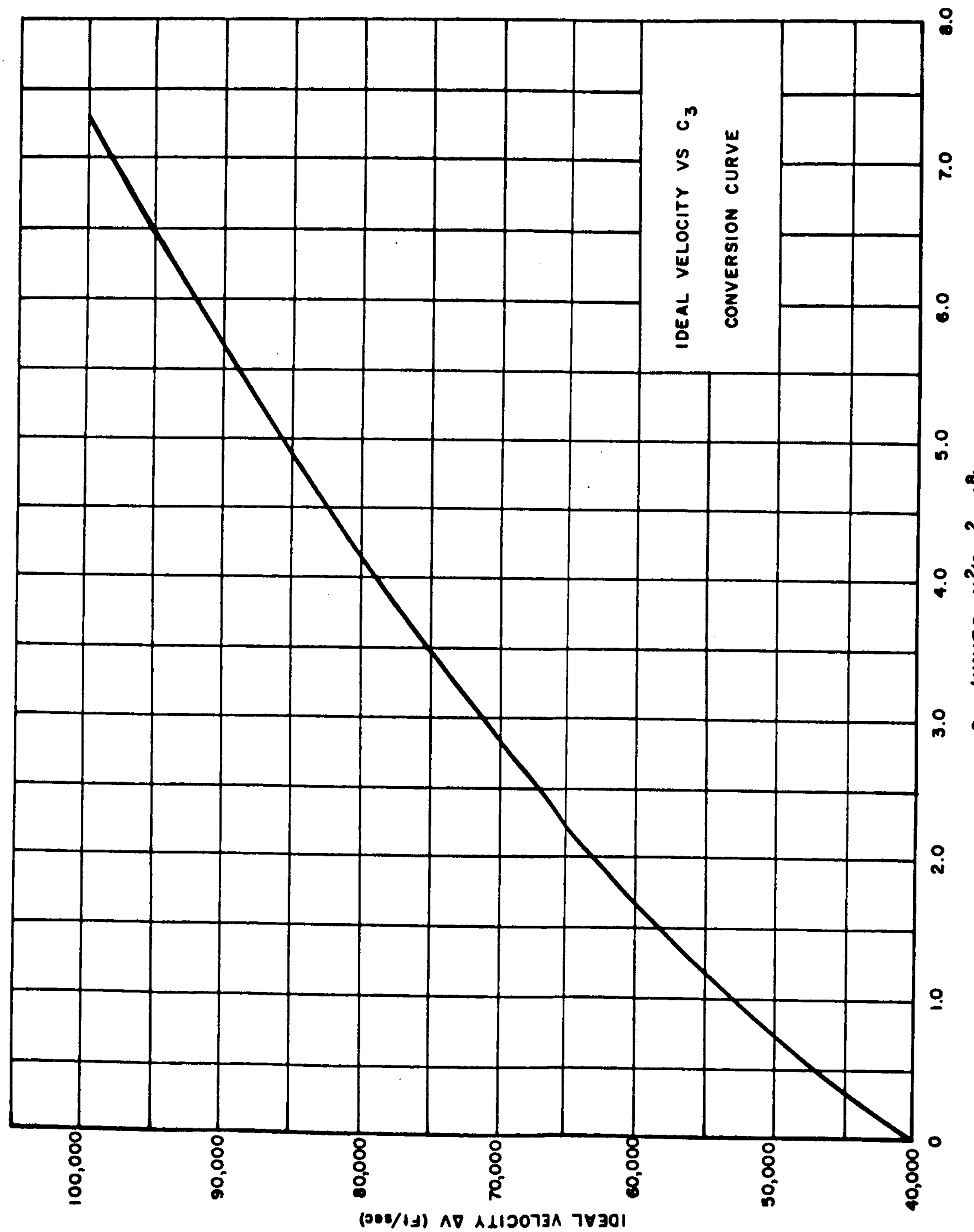
IDEAL VELOCITY VS C_3
CONVERSION CURVE
IDEAL VELOCITY ΔV (Ft/sec)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
C_3 (UNITS $M^2/Sec^2 \times 10^8$)
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

Figure A-5

Table A-1

OSCULATING ORBITAL ELEMENTS FOR COMET AREND

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
8/20/59	2,436,800.5	3.930	0.534	21.65	357.62	44.54	9/1/59
3/6/60	2,437,000.5	3.930	0.534	21.65	357.61	44.53	6/17/67
1/5/64	2,438,400.5	3.925	0.535	21.67	357.61	44.47	6/14/67
4/19/67	2,439,600.5	3.921	0.535	21.67	357.53	44.63	6/14/67
11/5/67	2,439,800.5	3.921	0.535	21.67	357.53	44.64	3/20/75
6/27/69	2,440,400.5	3.966	0.542	21.37	357.39	45.54	5/15/75
8/1/70	2,440,800.5	3.979	0.540	20.13	356.21	46.89	5/28/75
9/5/71	2,441,200.5	3.983	0.539	19.99	355.87	47.10	5/27/75
12/18/74	2,442,400.5	3.998	0.538	19.97	355.68	46.90	5/26/75
7/6/75	2,442,600.5	3.995	0.537	19.97	355.68	46.88	5/21/83
5/6/79	2,444,000.5	4.000	0.536	19.94	355.65	47.00	5/26/83
3/6/83	2,445,400.5	4.006	0.536	19.94	355.65	46.89	5/26/83
9/22/83	2,445,600.5	4.007	0.536	19.94	355.64	46.88	6/2/91
5/14/85	2,446,200.5	4.005	0.536	19.95	335.64	46.83	5/31/91

Table A-2

OSCULATING ORBITAL ELEMENTS FOR COMET AREND-RIGAUX

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
9/28/63	2,438,300.5	3.594	0.600	17.85	121.62	328.86	6/2/64
4/14/64	2,438,500.5	3.594	0.600	17.85	121.59	328.85	6/2/64
10/31/64	2,438,700.5	3.593	0.600	17.85	121.59	328.86	3/27/71
7/28/67	2,439,700.5	3.597	0.600	17.85	121.56	328.98	3/31/71
11/9/70	2,440,900.5	3.601	0.599	17.84	121.56	328.92	4/1/71
5/28/71	2,441,100.5	3.600	0.599	17.84	121.56	328.92	1/29/78
9/9/74	2,442,300.5	3.599	0.598	17.84	121.54	328.93	1/27/78
12/22/77	2,443,500.5	3.598	0.599	17.86	121.53	328.98	1/26/78
7/10/78	2,443,700.5	3.597	0.599	17.86	121.53	328.96	11/22/84
4/5/81	2,444,700.5	3.598	0.598	17.85	121.55	328.97	11/22/84
7/18/84	2,445,900.5	3.602	0.598	17.85	121.56	328.90	11/22/84
2/3/85	2,446,100.5	3.602	0.598	17.85	121.56	328.89	9/24/91
8/22/85	2,446,300.5	3.601	0.598	17.85	121.56	328.87	9/23/91

Table A-3

OSCULATING ORBITAL ELEMENTS FOR COMET ASHBROOK-JACKSON

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
3/17/56	2,435,550.5	3.834	0.394	12.49	2.30	349.08	4/5/56
10/3/56	2,435,750.5	3.834	0.394	12.49	2.30	349.07	10/8/63
8/3/60	2,437,150.5	3.828	0.394	12.50	2.28	348.91	10/1/63
4/30/63	2,438,150.5	3.826	0.395	12.51	2.30	348.97	10/1/63
11/16/63	2,438,350.5	3.830	0.396	12.50	2.30	348.94	3/30/71
9/16/67	2,439,750.5	3.816	0.397	12.52	2.18	348.51	3/14/71
12/29/70	2,440.950.5	3.805	0.400	12.52	2.17	348.82	3/11/71
7/17/71	2,441,150.5	3.807	0.400	12.52	2.17	348.82	8/14/78
10/29/74	2,442,350.5	3.808	0.401	12.53	2.11	348.91	8/16/78
2/10/78	2,443,500.5	3.807	0.400	12.52	2.08	349.00	8/18/78
8/29/78	2,443,750.5	3.806	0.400	12.52	2.08	349.00	1/19/86
12/11/81	2,444,950.5	3.811	0.397	12.52	2.07	349.18	1/23/86
3/25/85	2,446,150.5	3.821	0.396	12.50	2.01	348.89	1/23/86

Table A-4

<u>OSCULATING ORBITAL ELEMENTS FOR COMET BORRELLY</u>

Epoch Calendar	Epoch Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
6/15/60	2,437,100.5	3.667	0.604	31.09	76.23	350.75	6/20/67
9/27/63	2,438,300.5	3.662	0.605	31.12	76.19	350.70	6/17/67
1/9/67	2,439,500.5	3.658	0.605	31.14	76.18	350.80	6/17/67
7/28/67	2,439,700.5	3.658	0.605	31.14	76.18	350.80	6/15/74
5/28/71	2,441,100.5	3.644	0.609	31.42	75.99	350.68	6/1/74
8/5/73	2,441,900.5	3.579	0.633	30.22	75.18	352.42	5/11/74
9/9/74	2,442,300.5	3.577	0.633	30.22	75.15	352.48	2/14/81
12/22/77	2,443,500.5	3.579	0.633	30.23	75.12	352.56	2/17/81
3/1/80	2,444,300.5	3.579	0.633	30.20	75.10	352.57	2/18/81
4/5/81	2,444,700.5	3.579	0.632	30.20	75.09	352.57	11/27/87
6/14/83	2,445,500.5	3.597	0.629	30.39	74.79	353.24	12/13/87
8/22/85	2,446,300.5	3.606	0.625	30.34	74.79	353.19	12/16/87

Table A-5

OSCULATING ORBITAL ELEMENTS FOR COMET BROOKS 2

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
8/3/60	2,437,150.5	3.561	0.505	5.573	176.89	197.10	3/7/67
6/3/64	2,438,550.5	3.563	0.506	5.576	176.87	197.19	3/10/67
2/28/67	2,439,550.5	3.561	0.505	5.574	176.83	197.25	3/11/67
9/16/67	2,439,750.5	3.561	0.505	5.574	176.82	197.29	11/29/73
12/29/70	2,440,950.5	3.604	0.495	5.571	176.64	198.32	1/3/74
9/24/73	2,441,950.5	3.618	0.491	5.553	176.29	198.16	1/4/74
4/12/74	2,442,150.5	3.616	0.491	5.553	176.29	198.17	11/20/80
1/6/77	2,443,150.5	3.621	0.491	5.552	176.28	198.30	11/25/80
5/25/81	2,444,750.5	3.625	0.490	5.547	176.23	198.23	10/22/87
2/19/84	2,445,750.5	3.623	0.490	5.549	176.23	198.1[illegible]	10/19/87
10/11/85	2,446,350.5	3.621	0.490	5.551	176.24	198.15	10/18/87

Table A-6

OSCULATING ORBITAL ELEMENTS FOR COMET COMAS SOLA

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/11/61	2,437,400.5	4.193	0.576	13.44	62.85	40.01	11/4/69
10/1/66	2,439,400.5	4.185	0.578	13.45	62.82	39.96	10/29/69
6/27/69	2,440,400.5	4.182	0.577	13.45	62.76	40.06	10/30/69
1/13/70	2,440,600.5	4.181	0.577	13.45	62.76	40.06	5/18/78
2/17/71	2,441,000.5	4.199	0.578	13.46	62.73	40.32	6/8/78
5/29/71	2,441,101.0	4.217	0.579	13.46	62.73	40.64	6/29/78
9/6/71	2,441,201.4	4.253	0.577	13.39	62.74	41.39	8/10/78
12/16/71	2,441,301.9	4.287	0.573	13.21	62.70	42.25	9/15/78
3/24/72	2,441,400.5	4.299	0.569	13.08	62.62	42.63	9/27/78
4/1/78	2,443,600.5	4.306	0.566	12.96	62.43	42.86	9/26/78
10/18/78	2,443,800.5	4.308	0.566	12.95	62.43	42.85	9/5/87
7/14/81	2,444,800.5	4.303	0.565	12.95	62.41	42.82	8/30/87
5/14/85	2,446,200.5	4.298	0.568	12.92	62.06	43.10	8/22/87

Table A-7

OSCULATING ORBITAL ELEMENTS FOR COMET DANIEL

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/15/64	2,438,500.5	3.692	0.550	20.13	68.52	10.97	4/21/64
10/31/64	2,438,700.5	3.692	0.550	20.13	68.52	10.98	5/25/71
2/13/68	2,439,900.5	3.697	0.549	20.12	68.52	11.09	5/30/71
5/28/71	2,441,100.5	3.701	0.549	20.11	68.49	11.02	5/31/71
12/14/71	2,441,300.5	3.700	0.549	20.11	68.49	11.01	7/12/78
6/5/77	2,443,300.5	3.692	0.550	20.13	68.51	10.99	7/7/78
7/10/78	2,443,700.5	3.692	0.550	20.13	68.50	11.02	8/10/85
10/22/81	2,444,900.5	3.688	0.550	20.13	68.48	10.92	8/5/85
2/3/85	2,446,100.5	3.683	0.552	20.13	68.46	11.02	8/2/85
8/22/85	2,446,300.5	3.684	0.552	20.13	68.46	11.02	8/28/92

Table A-8

OSCULATING ORBITAL ELEMENTS FOR COMET D'ARREST

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
9/28/63	2,438,300.5	3.544	0.614	18.08	143.61	174.51	10/15/63
4/14/64	2,438,500.5	3.545	0.614	18.08	143.59	174.51	6/18/70
7/28/67	2,439,700.5	3.523	0.621	18.33	143.40	174.31	5/29/70
2/13/68	2,439,900.5	3.481	0.639	18.39	143.39	174.91	5/13/70
4/23/70	2,440,700.5	3.398	0.652	17.01	141.77	178.36	5/13/70
11/9/70	2,440,900.5	3.399	0.652	17.01	141.77	178.37	8/18/76
1/17/73	2,441,700.5	3.398	0.652	17.03	141.74	178.38	8/18/76
5/1/76	2,442,900.5	3.396	0.652	17.03	141.72	178.45	8/18/76
11/17/76	2,443,100.5	3.397	0.652	17.03	141.71	178.47	11/22/82
4/1/78	2,443,600.5	3.395	0.654	17.15	141.36	178.66	11/21/82
10/18/78	2,443,800.5	3.385	0.658	17.44	140.96	178.80	11/13/82
3/17/79	2,443,950.5	3.366	0.665	18.31	140.35	178.97	10/27/82
5/6/79	2,444,000.5	3.357	0.668	19.06	140.01	178.97	10/16/82
8/14/79	2,444,100.5	3.374	0.656	20.89	139.57	178.21	9/26/82
10/22/81	2,444,900.5	3.457	0.619	20.03	139.06	177.18	10/13/82
11/26/82	2,445,300.5	3.455	0.619	20.02	139.00	177.25	3/15/89
12/31/83	2,445,700.5	3.456	0.619	20.02	138.99	177.26	3/16/89
8/22/85	2,446,300.5	3.456	0.619	20.03	138.97	177.30	3/17/89

Table A-9

OSCULATING ORBITAL ELEMENTS FOR COMET ENCKE

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
6/4/64	2,438,550.5	2.217	0.847	11.97	334.23	185.91	9/22/67
1/24/66	2,439,150.5	2.217	0.847	11.97	334.23	185.91	9/21/67
9/16/67	2,439,750.5	2.217	0.847	11.99	334.23	185.92	9/21/67
4/3/68	2,439,950.5	2.217	0.847	11.99	334.23	185.92	1/9/71
11/24/69	2,440,550.5	2.217	0.847	11.98	334.23	185.94	1/9/71
12/29/70	2,440,950.5	2.217	0.847	11.97	334.21	185.95	1/9/71
7/17/71	2,441,150.5	2.217	0.847	11.97	334.21	185.95	4/29/74
3/8/73	2,441,750.5	2.217	0.847	11.98	334.21	185.93	4/28/74
4/12/74	2,442,150.5	2.217	0.847	11.98	334.22	185.93	4/28/74
10/29/74	2,442,350.5	2.217	0.847	11.98	334.22	185.94	8/16/77
6/20/76	2,442,950.5	2.218	0.847	11.94	334.22	185.96	8/16/77
7/25/77	2,443,350.5	2.219	0.847	11.94	334.21	185.96	8/16/77
2/10/78	2,443,550.5	2.219	0.847	11.94	334.20	185.96	12/6/80
10/3/79	2,444,150.5	2.219	0.847	11.95	334.20	185.96	12/6/80
11/6/80	2,444,550.5	2.218	0.847	11.95	334.19	185.98	12/6/80
5/25/81	2,444,750.5	2.218	0.847	11.94	334.19	185.99	3/27/84
1/15/83	2,445,350.5	2.219	0.846	11.93	334.19	186.00	3/27/84
2/19/84	2,445,750.5	2.219	0.846	11.93	334.18	186.00	3/27/84
9/6/84	2,445,950.5	2.219	0.846	11.93	334.17	186.00	7/18/87
11/30/85	2,446,400.5	2.217	0.848	11.98	334.15	185.97	7/17/87

Table A-10

OSCULATING ORBITAL ELEMENTS FOR COMET FAYE

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
5/16/62	2,437,800.5	3.790	0.576	9.10	199.12	203.56	9/29/69
3/15/66	2,439,200.5	3.797	0.576	9.09	199.10	203.71	10/6/69
6/27/69	2,440,400.5	3.800	0.575	9.08	199.04	203.68	10/7/69
1/13/70	2,440,600.5	3.800	0.575	9.08	199.04	203.68	3/4/77
11/13/73	2,442,000.5	3.796	0.575	9.09	199.06	203.61	2/28/77
2/25/77	2,443,200.5	3.793	0.576	9.09	199.08	203.67	2/27/77
9/13/77	2,443,400.5	3.792	0.576	9.09	199.07	203.66	7/17/84
12/26/80	2,444,600.5	3.788	0.576	9.10	199.06	203.55	7/12/84
4/9/84	2,445,800.5	3.778	0.578	9.09	198.98	203.84	7/9/84
10/26/84	2,446,000.5	3.779	0.578	9.09	198.98	203.84	11/14/91

Table A-11

OSCULATING ORBITAL ELEMENTS FOR COMET FINLAY

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
9/23/60	2,437,200.5	3.623	0.703	3.64	42.07	321.60	7/25/67
6/19/63	2,438,200.5	3.625	0.703	3.64	42.01	321.69	7/28/67
10/1/66	2,439,400.5	3.627	0.702	3.64	42.02	321.67	7/30/67
11/5/67	2,439,800.5	3.627	0.702	3.64	42.02	321.67	6/26/74
9/5/71	2,441,200.5	3.642	0.699	3.64	41.81	322.12	7/8/74
6/1/74	2,442,200.5	3.645	0.699	3.64	41.81	322.10	7/8/74
12/18/74	2,442,400.5	3.645	0.699	3.64	41.81	322.11	6/22/81
4/1/78	2,443,600.5	3.649	0.699	3.64	41.82	322.16	6/26/81
6/9/80	2,444,400.5	3.651	0.699	3.64	41.83	322.10	6/26/81
7/14/81	2,444,800.5	3.653	0.699	3.64	41.83	322.10	6/19/88
9/22/83	2,445,600.5	3.649	0.699	3.64	41.82	322.06	6/15/88
11/30/85	2,446,400.5	3.647	0.700	3.65	41.78	322.10	6/14/88

Table A-12

OSCULATING ORBITAL ELEMENTS FOR COMET FORBES

Epoch Calendar	Epoch Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
2/11/55	2,435,150.5	3.461	0.551	4.62	25.45	259.69	2/17/55
8/30/55	2,435,350.5	3.461	0.551	4.62	25.44	259.69	7/27/61
5/26/58	2,436,350.5	3.457	0.552	4.62	25.44	259.61	7/24/61
2/19/61	2,437,350.5	3.454	0.553	4.62	25.40	259.73	7/24/61
9/7/61	2,437,550.5	3.456	0.553	4.62	25.39	259.73	12/26/67
12/20/64	2,438,750.5	3.454	0.552	4.62	25.38	259.66	12/22/67
9/16/67	2,439,750.5	3.451	0.553	4.62	25.29	259.81	12/21/67
4/3/68	2,439,950.5	3.452	0.554	4.62	25.29	259.81	5/21/74
7/17/71	2,441,150.5	3.449	0.555	4.62	25.26	259.78	5/19/74
4/12/74	2,442,150.5	3.445	0.555	4.62	25.20	259.93	5/19/74
10/29/74	2,442,350.5	3.446	0.555	4.62	25.20	259.92	10/11/80
2/10/78	2,443,550.5	3.432	0.559	4.62	24.73	260.05	9/27/80
3/17/79	2,443,950.5	3.412	0.565	4.65	23.30	261.95	9/23/80
4/20/80	2,444,350.5	3.400	0.565	4.66	23.06	262.50	9/24/80
11/6/80	2,444,550.5	3.400	0.565	4.66	23.06	262.51	1/1/87
1/15/83	2,445,350.5	3.400	0.565	4.66	23.04	262.51	1/1/87
10/11/85	2,446,350.5	3.398	0.566	4.66	22.95	262.66	1/1/87

Table A-13

OSCULATING ORBITAL ELEMENTS FOR COMET GIACOBINI-ZINNER

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
10/8/59	2,436,850.5	3.453	0.729	30.91	196.03	172.84	10/26/59
4/25/60	2,437,050.5	3.453	0.729	30.91	196.03	172.84	3/27/66
1/20/63	2,438,050.5	3.452	0.730	30.95	195.98	172.87	3/27/66
10/16/65	2,439,050.5	3.450	0.729	30.95	195.97	172.92	3/27/66
5/4/66	2,439,250.5	3.449	0.729	30.95	195.96	172.92	8/22/72
8/16/69	2,440,450.5	3.441	0.731	32.31	195.39	172.83	8/3/72
10/31/69	2,440,526.5	3.454	0.727	32.54	195.37	172.47	7/31/72
5/12/72	2,441,450.5	3.489	0.715	31.71	195.13	171.88	8/3/72
11/28/72	2,441,650.5	3.489	0.715	31.71	195.13	171.89	2/9/79
3/12/76	2,442,850.5	3.491	0.715	31.74	195.09	171.95	2/11/79
12/7/78	2,443,850.5	3.491	0.714	31.70	195.07	171.95	2/11/79
6/25/79	2,444,050.5	3.491	0.714	31.70	195.06	171.96	8/21/85
7/29/80	2,444,450.5	3.497	0.714	31.78	194.91	172.20	8/27/85
2/14/81	2,444,650.5	3.503	0.712	31.921	194.75	172.47	9/1/85
9/2/81	2,444,850.5	3.507	0.710	31.980	194.71	172.58	9/4/85
7/3/85	2,446,250.5	3.517	0.707	31.888	194.70	172.47	9/4/85

Table A-14

OSCULATING ORBITAL ELEMENTS FOR COMET GRIGG-SKJELLERUP

Epoch Calendar	Epoch Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
5/30/61	2,437,450.5	2.888	0.703	17.61	215.41	356.33	12/30/61
12/16/61	2,437,650.5	2.888	0.703	17.61	215.41	356.33	12/30/61
7/4/62	2,437,850.5	2.889	0.703	17.61	215.39	356.36	11/28/66
6/19/63	2,438,200.5	2.889	0.705	17.81	215.01	356.67	11/29/66
9/28/63	2,438,301.0	2.887	0.707	18.10	214.67	356.95	11/29/66
11/17/63	2,438,351.2	2.886	0.708	18.44	214.39	357.22	11/29/66
1/6/64	2,438,401.4	2.885	0.709	19.11	213.96	357.68	11/30/66
2/26/64	2,438,451.7	2.893	0.706	20.32	213.41	358.40	12/7/66
4/16/64	2,438,501.9	2.916	0.694	21.41	213.08	358.99	12/22/66
9/11/64	2,438,650.5	2.956	0.671	21.45	213.03	359.12	1/11/67
11/20/66	2,439,450.5	2.971	0.663	21.04	212.72	359.11	1/15/67
6/8/67	2,439,650.5	2.971	0.663	21.04	212.72	359.12	2/29/72
8/16/69	2,440,450.5	2.972	0.663	21.06	212.70	359.16	3/1/72
10/25/71	2,441,250.5	2.970	0.663	21.06	212.69	359.22	3/1/72
5/12/72	2,441,450.5	2.970	0.663	21.06	212.69	359.23	4/14/77
7/21/74	2,442,250.5	2.967	0.663	21.06	212.68	359.17	4/11/77
9/28/76	2,443,050.5	2.963	0.665	21.09	212.69	359.25	4/9/77
4/16/77	2,443,250.5	2.962	0.665	21.09	212.68	359.27	5/16/82
6/25/79	2,444,050.5	2.960	0.665	21.11	212.66	359.24	5/14/82
3/21/82	2,445,050.5	2.958	0.666	21.13	212.67	359.27	5/13/82
10/7/82	2,445,250.5	2.959	0.666	21.12	212.67	359.27	6/15/87
7/3/85	2,446,250.5	2.961	0.665	21.10	212.68	359.29	6/16/87

Table A-15

OSCULATING ORBITAL ELEMENTS FOR COMET HARRINGTON 2

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
6/15/60	2,437,100.5	3.590	0.559	8.69	119.17	232.79	6/28/60
12/31/60	2,437,300.5	3.591	0.559	8.69	119.17	232.80	4/18/67
4/14/64	2,438,500.5	3.594	0.559	8.68	119.13	232.93	4/23/67
1/9/67	2,439,500.5	3.596	0.559	8.68	119.08	232.94	4/23/67
7/28/67	2,439,700.5	3.595	0.558	8.68	119.08	232.94	2/15/74
11/9/70	2,440,900.5	3.600	0.557	8.66	119.02	233.09	2/18/74
1/27/74	2,442,074.9	3.604	0.557	8.66	119.01	232.96	2/17/74
8/15/74	2,442,274.9	3.604	0.557	8.66	119.01	232.96	12/21/80
5/11/77	2,443,274.9	3.607	0.556	8.65	118.99	233.09	12/24/80
8/23/80	2,444,474.9	3.612	0.556	8.65	118.97	233.00	12/24/80
3/11/81	2,444,674.9	3.612	0.556	8.65	118.97	233.00	11/5/87
5/20/83	2,445,474.9	3.608	0.556	8.65	118.97	232.92	11/2/87
7/28/85	2,446,274.9	3.606	0.557	8.65	118.98	232.90	10/31/87

Table A-16

OSCULATING ORBITAL ELEMENTS FOR COMET HARRINGTON-ABELL

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
2/5/62	2,437,700.5	3.741	0.523	16.809	145.91	338.29	3/1/62
8/23/62	2,437,900.5	3.741	0.523	16.809	145.91	338.28	5/26/69
6/23/66	2,439,300.5	3.736	0.524	16.829	145.86	338.26	5/23/69
3/19/69	2,440,300.5	3.732	0.524	16.831	145.85	338.36	5/23/69
10/5/69	2,440,500.5	3.734	0.524	16.830	145.85	338.37	8/10/76
1/17/73	2,441,700.5	3.716	0.529	16.978	145.38	338.30	7/23/76
8/5/73	2,441,900.5	3.706	0.533	17.188	145.20	338.37	7/15/76
11/13/73	2,442,000.5	3.696	0.539	17.486	145.08	338.41	7/6/76
2/21/74	2,442,100.5	3.683	0.561	18.591	145.01	337.94	6/5/76
3/13/74	2,442,125.5	3.712	0.578	19.305	145.08	336.56	5/8/76
3/23/74	2,442,130.5	3.733	0.582	19.413	145.09	335.88	4/29/76
3/28/74	2,442,135.5	3.768	0.586	19.428	145.09	334.91	4/18/76
4/2/74	2,442,140.5	3.822	0.590	19.256	145.06	333.54	4/7/76
4/7/74	2,442,145.5	3.903	0.590	18.778	144.97	331.68	3/28/76
4/12/74	2,442,150.5	4.010	0.588	17.932	144.97	329.36	3/20/76
4/17/74	2,442,155.5	4.133	0.581	16.819	144.50	326.86	3/15/76

Table A-16 (Cont'd)

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/22/74	2,442,160.5	4.249	0.572	15.67	144.13	324.54	3/15/76
4/27/74	2,442,165.5	4.344	0.562	14.66	143.74	322.64	3/17/76
5/7/74	2,442,175.5	4.466	0.545	13.25	143.05	320.19	3/23/76
5/17/74	2,442,185.5	4.526	0.533	12.43	142.52	318.94	3/30/76
6/1/74	2,442,200.5	4.565	0.5211	11.75	141.99	318.08	4/5/76
9/9/74	2,442,300.5	4.581	0.499	10.76	140.77	317.64	4/19/76
3/28/75	2,442,500.5	4.555	0.492	10.57	140.25	318.14	4/23/76
10/14/75	2,442,700.5	4.541	0.490	10.55	140.13	318.36	4/23/71
5/1/76	2,442,900.5	4.535	0.490	10.55	140.12	318.42	12/20/85
4/5/81	2,444,700.5	4.546	0.488	10.55	140.09	318.65	1/1/86
8/22/85	2,446,300.5	4.556	0.488	10.54	140.11	318.47	1/1/86

Table A-17

OSCULATING ORBITAL ELEMENTS FOR COMET HONDA-MRKOS-PAJDUSAKOVA

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
2/24/64	2,438,450.5	3.005	0.815	13.20	233.12	184.13	7/7/64
9/11/64	2,438,650.5	3.005	0.815	13.20	233.12	184.13	9/23/69
6/8/67	2,439,650.5	3.008	0.815	13.18	233.12	184.17	9/25/69
8/16/69	2,440,450.5	3.010	0.814	13.17	233.10	184.11	9/25/69
3/4/70	2,440,650.5	3.010	0.814	13.17	233.09	184.18	12/16/74
4/8/71	2,441,050.5	3.024	0.813	13.23	233.01	184.53	12/28/74
7/21/74	2,442,250.5	3.033	0.809	13.14	232.98	184.57	12/31/74
2/6/75	2,442,450.5	3.033	0.809	13.13	232.98	184.57	4/13/80
11/2/77	2,443,450.5	3.035	0.809	13.14	232.96	184.61	4/15/80
1/11/80	2,444,250.5	3.036	0.809	13.12	232.93	184.63	4/15/80
7/29/80	2,444,450.5	3.036	0.809	13.12	232.92	184.64	7/30/85
1/16/83	2,445,351.5	3.001	0.829	13.94	232.90	184.28	7/7/85
2/14/83	2,445,380.5	2.983	0.841	13.93	232.90	184.23	6/24/85
2/24/83	2,445,390.5	2.973	0.848	13.69	232.78	184.31	6/16/85
3/6/83	2,445,400.5	2.961	0.857	12.99	232.37	184.63	6/5/85
3/16/83	2,445,410.5	2.950	0.867	11.22	231.10	185.75	5/22/85

Table A-17 (Cont'd)

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
3/20/83	2,445,414.5	2.947	0.871	10.057	230.00	186.75	5/16/85
3/23/83	2,445,417.5	2.947	0.873	9.018	228.76	187.90	5/12/85
3/26/83*	2,445,420.5	2.948	0.874	7.875	227.00	189.55	5/8/85
3/31/83	2,445,425.5	2.952	0.874	5.909	222.28	194.06	5/3/85
4/5/83	2,445,430.5	2.960	0.872	4.150	213.88	202.22	5/1/85
4/10/83	2,445,435.5	2.969	0.868	2.843	199.33	216.55	4/30/85
4/15/83	2,445,440.5	2.978	0.864	2.106	177.07	238.61	5/1/85
4/20/83	2,445,445.4	2.987	0.860	1.895	152.38	263.12	5/2/85
4/25/83	2,445,450.5	2.994	0.856	1.988	133.68	281.68	5/4/85
6/15/83	2,445,501.5	3.031	0.836	3.075	99.76	314.92	5/15/85
11/11/83	2,445,650.5	3.049	0.824	3.316	96.84	317.45	5/22/85
12/15/84	2,446,050.5	3.051	0.821	3.326	96.75	317.36	5/24/85
7/3/85	2,446,250.5	3.050	0.821	3.326	96.75	317.36	9/20/90
1/19/86	2,446,450.5	3.050	0.821	3.326	96.74	317.36	9/20/90

* Closest approach to Jupiter = 0.11 AU on 3/27/83

Table A-18

OSCULATING ORBITAL ELEMENTS FOR COMET JOHNSON

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
6/20/63	2,438,200.5	3.608	0.377	13.87	118.17	205.92	4/12/70
10/1/66	2,439,400.5	3.593	0.380	13.92	118.01	205.37	3/28/70
1/13/70	2,440,600.5	3.578	0.385	13.91	117.88	205.86	3/24/70
8/1/70	2,440,800.5	3.579	0.385	13.91	117.88	205.87	12/30/76
11/13/73	2,442,000.5	3.578	0.386	13.91	117.86	205.92	12/31/76
8/9/76	2,443,000.5	3.575	0.386	13.91	117.82	206.06	1/1/77
2/25/77	2,443,200.5	3.574	0.386	13.91	117.82	206.08	10/5/83
6/9/80	2,444,400.5	3.624	0.375	13.78	117.63	207.78	11/20/83
9/22/83	2,445,600.5	3.641	0.366	13.66	116.68	208.19	11/26/83
4/9/84	2,445,800.5	3.640	0.366	13.66	116.68	208.20	11/6/90
6/18/86	2,446,600.5	3.644	0.366	13.66	116.68	208.35	11/11/90

Table A-19

OSCULATING ORBITAL ELEMENTS FOR COMET KOPFF

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/15/64	2,438,500.5	3.418	0.555	4.71	120.91	161.91	5/18/64
10/31/64	2,438,700.5	3.418	0.555	4.71	120.91	161.93	9/11/70
12/5/65	2,439,100.5	3.430	0.555	4.72	120.70	162.48	9/24/70
6/23/66	2,439,300.5	3.438	0.552	4.73	120.54	162.87	10/1/70
4/23/70	2,440,700.5	3.456	0.547	4.73	120.45	162.72	10/6/70
11/9/70	2,440,900.5	3.454	0.547	4.73	120.44	162.73	3/8/77
2/21/74	2,442,100.5	3.459	0.547	4.73	120.40	162.89	3/13/77
11/17/76	2,443,100.5	3.460	0.546	4.73	120.39	162.87	3/14/77
6/5/77	2,443,300.5	3.460	0.546	4.73	120.39	162.87	8/20/83
9/17/80	2,444,500.5	3.460	0.545	4.73	120.38	162.86	8/19/83
6/14/83	2,445,500.5	3.463	0.545	4.73	120.37	162.78	8/18/83
12/31/83	2,445,700.5	3.462	0.545	4.73	120.36	162.77	1/26/90
8/22/85	2,446,300.5	3.465	0.545	4.73	120.36	162.85	1/29/90

Table A-20

OSCULATING ORBITAL ELEMENTS FOR COMET NEUJMIN 1

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
12/14/48	2,432,900.5	6.861	0.774	15.00	347.17	346.69	12/21/67
7/2/49	2,433,100.5	6.862	0.774	15.00	347.17	346.70	6/6/67
1/18/50	2,433,300.5	6.867	0.775	15.00	347.16	346.73	12/13/66
10/23/58	2,436,500.5	6.873	0.774	14.98	347.25	346.65	12/11/66
6/23/66	2,439,300.5	6.852	0.775	15.03	347.18	346.82	12/9/66
1/9/67	2,439,500.5	6.851	0.775	15.03	347.18	346.81	11/13/84
5/1/76	2,442,900.5	6.831	0.775	15.07	347.07	346.86	10/20/84
3/1/80	2,444,300.5	6.844	0.776	14.96	347.06	346.76	10/13/84
10/22/81	2,444,900.5	6.861	0.777	14.18	346.49	347.22	10/9/84
7/18/84	2,445,900.5	6.904	0.777	14.10	346.25	347.16	10/8/84
2/3/85	2,446,100.5	6.900	0.777	14.10	346.25	347.17	11/24/2002

Table A-21

OSCULATING ORBITAL ELEMENTS FOR COMET NEUJMIN 3

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
12/16/61	2,437,650.5	4.817	0.591	3.86	150.71	147.63	6/28/72
10/16/65	2,439,050.5	4.798	0.590	3.86	150.64	147.40	6/3/72
5/12/72	2,441,450.5	4.817	0.590	3.89	150.27	146.94	5/17/72
11/28/72	2,441,650.5	4.814	0.589	3.89	150.27	146.94	12/9/82
9/28/76	2,443,050.5	4.825	0.587	3.89	150.19	147.22	12/20/82
7/29/80	2,444,450.5	4.880	0.587	3.97	149.97	146.14	12/6/82
10/7/82	2,445,250.5	4.922	0.581	3.94	149.74	145.17	12/8/82
4/25/83	2,445,450.5	4.921	0.581	3.94	149.74	145.18	11/7/93
1/19/86	2,446,450.5	4.931	0.581	3.94	149.69	145.37	11/19/93

Table A-22

OSCULATING ORBITAL ELEMENTS FOR COMET PERRINE-MRKOS

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
2/5/62	2,437,700.5	3.556	0.644	17.74	240.27	165.95	2/11/62
8/23/62	2,437,900.5	3.557	0.644	17.74	240.27	165.96	10/27/68
12/5/65	2,439,100.5	3.559	0.644	17.75	240.23	166.06	10/30/68
8/31/68	2,440,100.5	3.561	0.643	17.74	240.21	166.05	10/31/68
3/19/69	2,440,300.5	3.560	0.643	17.74	240.21	166.07	7/20/75
7/1/72	2,441,500.5	3.577	0.638	17.80	239.96	166.59	8/2/75
3/28/75	2,442,500.5	3.582	0.639	17.79	239.95	166.50	8/2/75
10/14/75	2,442,700.5	3.581	0.639	17.79	239.95	166.50	5/12/82
1/26/79	2,443,900.5	3.586	0.638	17.78	239.95	166.58	5/16/82
5/10/82	2,445,100.5	3.590	0.637	17.76	239.95	166.51	5/16/82
11/26/82	2,445,300.5	3.589	0.637	17.76	239.95	116.50	3/4/89
8/22/85	2,446,300.5	3.587	0.637	17.77	239.92	166.48	3/1/89

Table A-23

OSCULATING ORBITAL ELEMENTS FOR COMET PONS-WINNECKE

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/15/64	2,438,500.5	3.410	0.639	22.33	92.88	172.01	7/9/70
7/28/67	2,439,700.5	3.422	0.636	22.34	92.81	172.31	7/18/70
4/23/70	2,440,700.5	3.426	0.636	22.32	92.79	172.23	7/18/70
11/9/70	2,440,900.5	3.426	0.636	22.32	92.79	172.23	11/19/76
2/21/74	2,442,100.5	3.430	0.635	22.32	92.77	172.36	11/24/76
11/17/76	2,443,100.5	3.432	0.635	22.30	92.75	172.34	11/24/76
6/5/77	2,443,300.5	3.432	0.635	22.30	92.75	172.34	4/4/83
3/1/80	2,444,300.5	3.431	0.634	22.30	92.75	172.33	4/2/83
11/26/82	2,445,300.5	3.432	0.635	22.31	92.75	172.31	4/2/83
6/14/83	2,445,500.5	3.432	0.635	22.31	92.75	172.30	8/10/89
8/22/85	2,446,300.5	3.434	0.634	22.30	92.76	172.37	8/12/89

Table A-24

OSCULATING ORBITAL ELEMENTS FOR COMET REINMUTH 1

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/7/58	2,436,300.5	3.883	0.478	8.40	123.56	12.92	11/18/65
12/31/60	2,437,300.5	3.850	0.489	8.60	122.88	12.44	10/18/65
7/19/61	2,437,500.5	3.814	0.500	8.74	122.85	11.47	9/11/65
2/4/62	2,437,700.5	3.801	0.503	8.65	122.72	10.15	8/7/65
9/27/63	2,438,300.5	3.856	0.490	8.31	121.60	9.48	8/6/65
5/19/65	2,438,900.5	3.867	0.487	8.29	121.15	9.43	8/6/65
12/5/65	2,439,100.5	3.865	0.487	8.29	121.15	9.44	3/13/73
10/5/69	2,440,500.5	3.871	0.486	8.28	121.14	9.59	3/19/73
1/17/73	2,441,700.5	3.876	0.486	8.28	121.10	9.50	3/20/73
8/5/73	2,441,900.5	3.875	0.485	8.28	121.10	9.48	11/4/80
6/5/77	2,443,300.5	3.868	0.487	8.29	121.09	9.36	10/28/80
9/17/80	2,444,500.5	3.863	0.487	8.29	121.10	9.50	10/28/80
4/5/81	2,444,700.5	3.865	0.488	8.29	121.09	9.50	6/3/88
12/31/83	2,445,700.5	3.853	0.488	8.30	120.99	9.23	5/21/88
8/22/85	2,446,300.5	3.842	0.493	8.31	121.00	9.15	5/13/88

Table A-25

OSCULATING ORBITAL ELEMENTS FOR COMET REINMUTH 2

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
11/11/60	2,437,250.5	3.558	0.457	6.99	296.16	45.50	11/24/60
5/30/61	2,437,450.5	3.558	0.457	6.99	296.16	45.51	8/12/67
4/4/64	2,438,490.5	3.563	0.456	6.98	296.14	45.68	8/17/67
6/8/67	2,439,650.5	3.566	0.455	6.98	296.08	45.65	8/18/67
12/25/67	2,439,850.5	3.566	0.455	6.98	296.08	45.65	5/12/74
4/8/71	2,441,050.5	3.563	0.455	6.98	296.08	45.55	5/8/74
1/2/74	2,442,050.5	3.566	0.456	6.98	296.09	45.47	5/8/74
7/21/74	2,442,250.5	3.566	0.456	6.98	296.08	45.43	1/30/81
11/2/77	2,443,450.5	3.566	0.455	6.97	296.05	45.50	1/30/81
7/29/80	2,444,450.5	3.569	0.455	6.97	296.04	45.42	1/29/81
2/14/81	2,444,650.5	3.570	0.455	6.97	296.04	45.41	10/29/87
11/11/83	2,445,650.5	3.567	0.455	6.97	296.04	45.31	10/26/87
8/7/86	2,446,650.5	3.563	0.456	6.97	296.02	45.41	10/25/87

Table A-26

OSCULATING ORBITAL ELEMENTS FOR COMET SCHAUMASSE

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/25/60	2,437,050.5	4.060	0.705	12.02	86.25	51.94	6/21/68
8/8/63	2,438,250.5	4.072	0.704	11.95	86.14	52.31	7/4/68
12/25/67	2,439,850.5	4.066	0.704	11.93	85.96	52.56	7/3/68
7/12/68	2,440,050.5	4.066	0.705	11.93	85.96	52.57	9/14/76
7/21/74	2,442,250.5	4.064	0.707	11.87	85.04	53.34	9/3/76
2/6/75	2,442,450.5	4.077	0.708	11.81	82.43	55.71	9/2/76
8/25/75	2,442,650.5	4.083	0.705	11.84	80.76	57.09	9/3/76
3/12/76	2,442,850.5	4.078	0.705	11.86	80.55	57.27	9/3/76
9/28/76	2,443,050.5	4.075	0.704	11.86	80.55	57.29	11/25/84
9/2/81	2,444,850.5	4.082	0.704	11.84	80.44	57.47	12/3/84
5/29/84	2,445,850.5	4.085	0.703	11.84	80.40	57.44	12/4/84
12/15/84	2,446,050.5	4.086	0.703	11.84	80.40	57.43	3/8/93
1/19/86	2,446,450.5	4.085	0.703	11.84	80.40	57.44	3/7/93

Table A-27

OSCULATING ORBITAL ELEMENTS FOR COMET SCHWASSMANN-WACHMANN 1

Epoch Calendar	Epoch Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
6/11/57	2,436,000.5	6.376	0.132	9.49	321.60	355.84	6/18/73
4/10/61	2,437,400.5	6.395	0.133	9.48	321.54	356.51	7/22/73
6/19/63	2,438,200.5	6.408	0.133	9.48	321.55	357.33	8/18/73
8/27/65	2,439,000.5	6.419	0.131	9.47	321.57	357.37	8/27/73
12/9/68	2,440,200.5	6.416	0.133	9.46	321.54	356.99	8/13/73
8/1/70	2,440,800.5	6.390	0.135	9.45	321.18	359.13	8/29/73
9/5/71	2,441,200.5	6.353	0.135	9.49	320.56	2.44	9/30/73
10/9/72	2,441,600.5	6.278	0.130	9.62	319.86	7.40	11/21/73
4/27/73	2,441,800.5	6.215	0.122	9.71	319.70	10.33	12/26/73
11/13/73	2,442,000.5	6.131	0.111	9.75	319.68	13.16	1/30/74
6/1/74	2,442,200.5	6.043	0.098	9.69	319.57	15.41	1/2/89
12/18/74	2,442,400.5	5.969	0.086	9.55	319.04	16.97	10/7/88
7/6/75	2,442,600.5	5.921	0.078	9.40	317.99	18.32	8/6/88
1/22/76	2,442,800.5	5.898	0.072	9.29	316.60	20.33	7/12/88
8/9/76	2,443,000.5	5.895	0.069	9.26	315.17	23.48	7/27/88

Table A-27 (Cont'd)

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
2/25/77	2,443,200.5	5.908	0.066	9.28	313.96	27.79	9/19/88
9/13/77	2,443,400.5	5.932	0.063	9.34	313.14	32.74	12/8/88
4/1/78	2,443,600.5	5.958	0.061	9.38	312.73	37.52	3/5/89
10/18/78	2,443,800.5	5.983	0.058	9.41	312.59	41.51	5/21/89
5/6/79	2,444,000.5	6.003	0.055	9.42	312.57	44.40	7/20/89
11/22/79	2,444,200.5	6.019	0.053	9.41	312.58	46.30	8/29/89
6/9/80	2,444,400.5	6.031	0.051	9.40	312.58	47.32	9/22/89
7/14/81	2,444,800.5	6.047	0.048	9.37	312.54	47.69	10/7/89
10/26/84	2,446,000.5	6.064	0.046	9.35	312.32	45.03	9/1/89
5/14/85	2,446,200.5	6.063	0.046	9.35	312.30	45.01	8/30/89

Table A-28

OSCULATING ORBITAL ELEMENTS FOR COMET SCHWASSMANN-WACHMANN 2

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
9/7/61	2,437,550.5	3.494	0.383	3.73	126.03	357.72	3/18/68
12/20/64	2,438,750.5	3.490	0.383	3.73	126.01	357.57	3/13/68
9/16/67	2,439,750.5	3.486	0.384	3.73	126.02	357.69	3/13/68
4/3/68	2,439,950.5	3.488	0.384	3.73	126.02	357.68	9/17/74
12/29/70	2,440,950.5	3.483	0.385	3.73	125.99	357.46	9/12/74
4/12/74	2,442,150.5	3.484	0.385	3.73	126.00	357.36	9/10/74
10/29/74	2,442,350.5	3.485	0.385	3.73	126.00	357.34	3/14/81
2/10/78	2,443,550.5	3.484	0.387	3.73	125.97	357.34	3/14/81
11/6/80	2,444,550.5	3.480	0.387	3.73	125.97	357.48	3/14/81
5/25/81	2,444,750.5	3.481	0.387	3.73	125.97	357.50	9/11/87
8/3/83	2,445,550.5	3.474	0.390	3.74	125.74	357.29	9/5/87
10/11/85	2,446,350.5	3.454	0.397	3.76	125.73	357.42	8/26/87

Table A-29

OSCULATING ORBITAL ELEMENTS FOR COMET TEMPEL 2

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
5/16/62	2,437,800.5	3.024	0.549	12.48	119.28	191.03	8/14/67
2/8/65	2,438,800.5	3.023	0.548	12.48	119.28	191.00	8/13/67
4/19/67	2,439,600.5	3.025	0.548	12.48	119.27	190.95	8/13/67
11/5/67	2,439,800.5	3.026	0.548	12.47	119.27	190.95	11/16/72
8/1/70	2,440,800.5	3.023	0.548	12.48	119.27	190.88	11/14/72
10/9/72	2,441,600.5	3.024	0.549	12.48	119.27	190.85	11/13/72
4/27/73	2,441,800.5	3.024	0.549	12.48	119.27	190.85	2/16/78
7/6/75	2,442,600.5	3.026	0.548	12.48	119.27	190.93	2/18/78
9/13/77	2,443,400.5	3.028	0.548	12.47	119.25	190.91	2/19/78
4/1/78	2,443,600.5	3.028	0.548	12.47	119.25	190.90	5/28/83
12/26/80	2,444,600.5	3.032	0.545	12.45	119.25	190.97	5/30/83
3/6/83	2,445,400.5	3.036	0.545	12.44	119.16	190.89	5/30/83
9/22/83	2,445,600.5	3.035	0.545	12.44	119.16	190.90	9/12/88
5/14/85	2,446,200.5	3.037	0.545	12.44	119.15	190.95	9/13/88

Table A-30

OSCULATING ORBITAL ELEMENTS FOR COMET TUTTLE

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
3/14/53	2,434,450.5	5.741	0.821	54.47	269.75	206.94	7/12/53
9/29/53	2,434,650.5	5.741	0.821	54.47	269.75	206.93	4/15/67
4/25/60	2,437,050.5	5.749	0.821	54.31	269.71	206.97	4/23/67
11/20/66	2,439,450.5	5.747	0.822	54.38	269.80	206.92	4/16/67
6/8/67	2,439,650.5	5.748	0.822	54.38	269.79	206.92	1/25/81
7/21/74	2,442,250.5	5.739	0.821	54.36	269.83	206.81	1/7/81
7/29/80	2,444,450.5	5.725	0.823	54.47	269.89	206.90	1/5/81
2/14/81	2,444,650.5	5.723	0.823	54.47	269.89	206.90	9/15/94
11/11/83	2,445,650.5	5.700	0.822	54.58	269.87	206.78	8/14/94
12/15/84	2,446,050.5	5.689	0.822	54.58	269.87	206.70	7/30/94

Table A-31

OSCULATING ORBITAL ELEMENTS FOR COMET TUTTLE-GIACOBINI-KRESAK

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
8/15/56	2,435,700.5	3.110	0.641	13.78	165.64	37.93	10/31/56
3/2/57	2,435,900.5	3.110	0.640	13.78	165.64	37.93	4/26/62
11/27/59	2,436,900.5	3.113	0.640	13.77	165.61	38.01	4/28/62
2/4/62	2,437,700.5	3.114	0.640	13.77	165.56	38.02	4/29/62
8/23/63	2,437,900.5	3.114	0.640	13.77	165.56	38.03	10/27/67
5/19/65	2,438,900.5	3.134	0.635	13.63	165.35	38.64	11/12/67
7/28/67	2,439,700.5	3.139	0.634	13.63	165.27	38.59	11/12/67
2/13/68	2,439,900.5	3.138	0.634	13.63	165.27	38.59	6/4/73
11/9/70	2,440,900.5	3.141	0.634	13.62	165.24	38.68	6/6/73
1/17/73	2,441,700.5	3.141	0.634	13.61	165.17	38.76	6/7/73
8/5/73	2,441,900.5	3.140	0.634	13.61	165.16	38.77	12/30/78
3/28/75	2,442,500.5	3.137	0.643	13.41	164.81	38.89	1/7/79
7/8/75	2,442,601.9	3.125	0.659	11.61	160.96	42.55	1/5/79
10/14/75	2,442,700.5	3.134	0.654	10.39	156.80	46.69	1/9/79
5/1/76	2,442,900.5	3.147	0.646	9.96	154.56	48.84	1/13/79

Table A-31 (Cont'd)

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
7/10/78	2,443,700.5	3.162	0.641	9.87	153.48	49.55	1/15/79
1/26/79	2,443,900.5	3.161	0.641	9.87	153.47	49.55	8/29/84
10/22/81	2,444,900.5	3.162	0.641	9.87	153.46	49.60	8/31/84
7/18/84	2,445,900.5	3.161	0.641	9.87	153.40	49.69	8/31/84
2/3/85	2,446,100.5	3.162	0.641	9.87	153.40	49.70	4/16/90
8/22/85	2,446,300.5	3.161	0.641	9.87	153.39	49.66	4/15/90

Table A-32

OSCULATING ORBITAL ELEMENTS FOR COMET VAISALA 1

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/25/60	2,437,050.5	4.782	0.636	11.29	135.43	44.44	5/10/60
11/11/60	2,437,250.5	4.785	0.636	11.29	135.43	44.47	10/28/70
5/31/61	2,437,450.5	4.802	0.637	11.31	135.38	44.63	11/18/70
9/7/61	2,437,550.5	4.829	0.639	11.36	135.31	44.94	12/22/70
10/2/61	2,437,575.5	4.844	0.639	11.38	135.28	45.11	1/9/71
10/27/61	2,437,600.5	4.865	0.640	11.42	135.25	45.39	2/5/71
11/21/61	2,437,625.5	4.898	0.641	11.48	135.21	45.85	3/18/71
12/16/61	2,437,650.5	4.944	0.641	11.55	135.17	46.53	5/13/71
1/10/61	2,437,675.5	4.992	0.639	11.61	135.15	47.35	7/11/71
2/4/62	2,437,700.5	5.028	0.636	11.63	135.15	48.03	8/23/71
3/1/63	2,437,725.5	5.047	0.634	11.62	135.15	48.47	9/14/71
7/4/62	2,437,850.5	5.064	0.628	11.55	135.13	49.09	10/1/71
12/1/62	2,438,000.5	5.064	0.626	11.52	135.10	49.20	9/28/71
9/11/64	2,438,650.5	5.059	0.625	11.50	135.07	49.15	9/20/71
11/20/66	2,439,450.5	5.050	0.627	11.50	135.04	49.14	9/13/71

Table A-32 (Cont'd)

Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/8/71	2,441,050.5	5.031	0.629	11.49	134.76	49.69	9/13/71
10/25/71	2,441,250.5	5.031	0.629	11.49	134.76	49.70	12/25/82
11/29/72	2,441,650.5	5.039	0.630	11.52	134.66	49.69	1/4/83
1/17/73	2,441,700.5	5.036	0.631	11.53	134.64	49.62	12/31/82
6/16/73	2,441,850.5	5.009	0.633	11.61	134.61	49.15	11/30/82
8/5/73	2,441,900.5	4.995	0.633	11.64	134.62	48.90	11/12/82
9/24/73	2,441,950.5	4.978	0.634	11.66	134.63	48.63	10/23/82
11/13/73	2,442,000.5	4.963	0.634	11.67	134.63	48.38	10/3/82
1/2/74	2,442,050.5	4.950	0.634	11.67	134.63	48.18	9/17/82
7/21/74	2,442,250.5	4.928	0.633	11.64	134.58	47.92	8/18/82
8/25/75	2,442,650.5	4.924	0.631	11.60	134.50	47.89	8/8/82
1/11/80	2,444,250.5	4.916	0.633	11.61	134.56	47.80	8/1/82
3/21/82	2,445,050.5	4.910	0.633	11.61	134.54	47.93	8/1/82
10/7/82	2,445,250.5	4.912	0.633	11.61	134.53	47.93	6/21/93
5/29/84	2,445,850.5	4.901	0.633	11.63	134.49	47.81	6/7/93
7/3/85	2,446,250.5	4.892	0.633	11.63	134.50	47.65	5/27/93

Table A-33

OSCULATING ORBITAL ELEMENTS FOR COMET WHIPPLE

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/30/63	2,438,150.5	3.819	0.353	10.25	188.39	189.98	10/14/70
8/12/66	2,439,350.5	3.816	0.351	10.24	188.40	189.98	10/10/70
6/12/70	2,440,750.5	3.821	0.351	10.24	188.39	189.81	10/10/70
12/29/70	2,440,950.5	3.822	0.351	10.24	188.39	189.80	3/31/78
10/29/74	2,442,350.5	3.818	0.352	10.25	188.36	189.73	3/28/78
2/10/78	2,443,550.5	3.812	0.352	10.25	188.34	189.96	3/28/78
8/29/78	2,443,750.5	3.812	0.352	10.25	188.34	189.98	9/6/85
4/20/80	2,444,350.5	3.838	0.353	10.32	187.85	191.41	10/7/85
11/6/80	2,444,550.5	3.867	0.351	10.52	187.34	193.24	11/12/85
2/15/81	2,444,651.5	3.894	0.347	10.69	187.12	194.66	12/14/85
5/1/81	2,444,726.5	3.924	0.340	10.80	187.04	195.90	1/15/86
7/15/81	2,444,801.5	3.960	0.331	10.85	187.03	197.13	2/21/86
9/3/81	2,444,851.5	3.985	0.324	10.84	187.02	197.86	3/16/86
11/17/81	2,444,926.5	4.021	0.314	10.75	186.97	198.74	4/16/86
2/25/82	2,445,026.5	4.060	0.302	10.58	186.75	199.51	5/15/86
11/2/82	2,445,276.5	4.119	0.283	10.19	185.75	200.35	6/15/86
1/15/83	2,445,350.5	4.131	0.279	10.11	185.40	200.48	6/19/86
9/6/84	2,445,950.5	4.185	0.266	9.87	182.56	201.21	6/25/86

Table A-34

OSCULATING ORBITAL ELEMENTS FOR COMET WIRTANEN

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/11/61	2,437,400.5	3.543	0.543	13.39	86.48	343.49	4/15/61
10/27/61	2,437,600.5	3.544	0.543	13.39	86.47	343.49	12/16/67
2/8/65	2,438,800.5	3.541	0.545	13.40	86.42	343.51	12/15/67
11/5/67	2,439,800.5	3.538	0.544	13.40	86.41	343.59	12/15/67
5/23/68	2,440,000.5	3.539	0.544	13.40	86.41	343.61	8/13/74
2/18/71	2,441,000.5	3.519	0.552	13.61	85.68	343.81	7/27/74
12/14/71	2,441,300.5	3.470	0.574	14.17	85.32	334.47	7/5/74
4/17/72	2,441,425.5	3.346	0.615	14.19	85.25	347.43	6/16/74
7/1/72	2,441,500.5	3.289	0.622	13.22	84.78	349.75	6/24/74
10/9/72	2,441,600.5	3.274	0.618	12.61	84.23	350.85	7/2/74
2/11/73	2,441,725.5	3.269	0.615	12.39	83.87	351.32	7/5/74
6/1/74	2,442,200.5	3.258	0.614	12.30	83.58	351.73	7/6/74
12/18/74	2,442,400.5	3.259	0.614	12.30	83.58	351.73	5/24/80
9/13/77	2,443,400.5	3.260	0.614	12.31	83.55	351.79	5/25/80
11/22/79	2,444,200.5	3.259	0.614	12.30	83.54	351.83	5/26/80
6/9/80	2,444,400.5	3.258	0.614	12.30	83.54	351.84	4/13/86
9/22/83	2,445,600.5	3.224	0.631	12.69	82.97	352.14	3/25/86
4/9/84	2,445,800.5	3.152	0.656	12.36	82.73	354.08	3/18/86
10/26/84	2,446,000.5	3.125	0.655	11.70	81.89	355.76	3/24/86
11/30/85	2,446,400.5	3.114	0.653	11.60	81.55	365.24	3/26/86

Table A-35

OSCULATING ORBITAL ELEMENTS FOR COMET WOLF 1

Epoch Calendar	Epoch Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
3/22/59	2,436,650.5	4.142	0.395	27.30	203.90	161.08	8/25/67
8/8/63	2,438,250.5	4.143	0.396	27.32	203.83	161.18	8/28/67
6/8/67	2,439,650.5	4.142	0.395	27.31	203.80	161.26	8/30/67
12/25/67	2,439,850.5	4.141	0.395	27.31	203.80	161.25	2/1/76
10/25/71	2,441,250.5	4.137	0.394	27.31	203.80	161.13	1/26/76
8/25/75	2,442,650.5	4.135	0.395	27.33	203.81	161.17	1/25/76
3/12/76	2,442,850.5	4.140	0.396	27.33	203.81	161.13	6/27/84
7/29/80	2,444,450.5	4.123	0.397	27.41	203.61	160.68	6/6/84
5/29/84	2,445,850.5	4.072	0.407	27.51	203.52	162.14	5/31/84
12/15/84	2,446,050.5	4.073	0.407	27.51	203.52	162.16	8/20/92
7/3/85	2,446,250.5	4.074	0.407	27.51	203.51	162.18	8/21/92

Table A-36

OSCULATING ORBITAL ELEMENTS FOR COMET WOLF-HARRINGTON

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
12/20/64	2,438,750.5	3.495	0.538	18.46	254.21	187.03	2/14/65
7/8/65	2,438,950.5	3.494	0.538	18.46	254.21	187.02	8/28/71
10/20/68	2,440,150.5	3.497	0.537	18.44	254.22	187.09	8/31/71
7/17/71	2,441,150.5	3.501	0.537	18.44	254.20	187.02	8/31/71
2/2/72	2,441,350.5	3.500	0.537	18.44	254.20	187.01	3/19/78
5/17/75	2,442,550.5	3.496	0.537	18.45	254.19	186.93	3/15/78
2/10/78	2,443,550.5	3.494	0.538	18.46	254.21	186.99	3/14/78
8/29/78	2,443,750.5	3.494	0.538	18.46	254.20	186.97	9/24/84
12/11/81	2,444,950.5	3.493	0.537	18.45	254.21	186.92	9/22/84
9/6/84	2,445,950.5	3.495	0.538	18.45	254.21	186.87	9/21/84
3/25/85	2,446,150.5	3.495	0.538	18.45	254.20	186.87	4/5/91
10/11/85	2,446,350.5	3.495	0.538	18.45	254.20	186.85	4/4/91

Table A-37

OSCULATING ORBITAL ELEMENTS FOR COMET HALLEY

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
4/19/10*	2,418,781.5	17.947	0.967	162.21	57.84	111.72	5/1/86
1/13/13	2,419,781.5	17.911	0.967	162.22	57.90	111.78	2/5/86
10/10/15	2,420,781.5	17.998	0.967	162.22	58.27	112.19	8/29/86
7/6/18	2,421,781.5	17.970	0.968	162.21	58.43	112.19	6/27/86
4/1/21	2,422,781.5	17.888	0.968	162.24	57.83	111.54	12/11/85
12/27/23	2,423,781.5	17.877	0.967	162.27	57.41	111.25	11/11/85
9/22/26	2,424,781.5	17.923	0.967	162.23	57.95	111.87	3/2/86
6/18/29	2,425,781.5	17.933	0.967	162.17	58.64	112.46	4/6/86
3/14/32	2,426,781.5	17.901	0.968	162.22	58.14	111.90	1/12/86
12/9/34	2,427,781.5	17.894	0.967	162.28	57.45	111.27	12/13/85
9/4/37	2,428,781.5	17.915	0.966	162.24	57.82	111.70	2/8/86
5/31/40	2,429,781.5	17.922	0.967	162.13	58.90	112.73	3/22/86
2/25/43	2,430,781.5	17.904	0.968	162.15	58.76	112.54	2/1/86
11/21/45	2,431,781.5	17.902	0.968	162.26	57.74	111.54	12/21/85
5/14/51	2,433,781.5	17.908	0.967	162.18	58.37	112.18	2/7/86
2/7/54	2,434,781.5	17.900	0.968	162.14	58.67	112.48	1/22/86
11/3/56	2,435,781.5	17.913	0.968	162.27	57.78	111.60	12/27/85

* Porter (1961)

Table A-37 (Cont'd)

Epoch							
Calendar	Julian	a (AU)	e	i (deg)	Ω (deg)	w (deg)	T_p (Next Perihelion)
7/31/59	2,436,781.5	17.925	0.967	162.34	57.28	111.06	1/1/86
4/26/62	2,437,781.5	17.906	0.966	162.23	57.97	111.73	1/24/86
1/20/65	2,438,781.5	17.884	0.967	162.11	58.75	112.58	1/24/86
10/17/67	2,439,781.5	17.911	0.968	162.18	58.34	112.19	1/9/86
7/13/70	2,440,781.5	17.941	0.967	162.28	57.74	111.53	1/6/86
4/8/73	2,441,781.5	17.916	0.967	162.25	57.93	111.66	1/13/86
1/3/76	2,442,781.5	17.875	0.967	162.13	58.53	112.35	1/14/86
9/29/78	2,443,781.5	17.937	0.968	162.15	58.43	112.32	1/9/86
6/25/81	2,444,781.5	18.035	0.968	162.24	58.06	111.85	1/7/86
3/21/84	2,445,781.5	18.003	0.967	162.26	58.00	111.69	1/8/86
11/11/85	2,446,381.5	17.929	0.967	162.25	58.02	111.74	1/8/86
2/19/86	2,446,481.5	17.930	0.967	162.25	58.02	111.74	12/12/2061
12/16/86	2,446,781.5	17.974	0.967	162.25	58.05	111.77	3/24/2062
7/4/87	2,446,981.5	17.994	0.967	162.25	58.08	111.79	5/9/2062
1/20/88	2,447,181.5	18.004	0.967	162.25	58.11	111.81	5/31/2062
8/7/88	2,447,381.5	18.000	0.968	162.25	58.13	111.80	5/23/2062
2/23/89	2,447,581.5	17.987	0.968	162.25	58.13	111.77	4/22/2062
9/11/89	2,447,781.5	17.967	0.968	162.25	58.11	111.73	3/8/2062
3/30/90	2,447,981.5	17.942	0.968	162.25	58.07	111.66	1/9/2062
10/16/90	2,448,181.5	17.918	0.968	162.25	58.02	111.59	11/13/2061
5/4/91	2,448,381.5	17.892	0.968	162.26	57.95	111.51	9/14/2061
11/20/91	2,448,581.5	17.871	0.968	162.26	57.88	111.44	7/28/2061

APPENDIX 2

NOMENCLATURE

Table A-38 defines the symbols used in this report.

Table A-38

NOMENCLATURE

a	Semi-major axis of comet orbit
C_3	$(VHL)^2$
e	Eccentricity of comet orbit
HCA	The heliocentric central angle, the angle between the position vector R_L of the Earth at time of the launch and the position vector R_p of the target at time of arrival of the spacecraft.
i	Inclination of comet orbit
q	Perihelion distance of comet orbit
R	Distance from the Sun
RC	The communications distance, or distance between the Earth and the target at time of arrival of the spacecraft at the target
T	Period of comet orbit
TF	Time of flight for a mission
T_p	Perihelion date of comet
VHL	Launch hyperbolic excess speed: the difference between the spacecraft's velocity in heliocentric coordinates after Earth escape and the Earth's velocity in its orbit at the same time.
VHP	Closing velocity (hyperbolic excess speed at the target): spacecraft to target velocity difference at arrival time.

Table A-38

(Cont'd)

ΔV	Ideal velocity: the total velocity increment which must be given to a spacecraft leaving Earth: $$\Delta V = \sqrt{(36,178)^2 + (VHL)^2} + 4000 \text{ ft/sec}$$ Here 36,178 ft/sec is the characteristic velocity for Earth escape, launching from Cape Kennedy, and 4000 ft/sec is a correction for gravitational and frictional losses during launch.
w	Argument of perihelion of comet orbit
$\overline{w}$	Longitude of perihelion of comet orbit
Ω	Longitude of the ascending node of comet orbit
M	Mean anomaly of comet in its orbit

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ASC/IITRI Report No. T-7 "Perturbation, Sighting and Trajectory Analysis for Periodic Comets: 1965-1975"

Page iv - fifth line from bottom: (20-30 km/sec) should be (65-70 km/sec)

Page 11 (Table 3) VHP for the Halley flights in 1/85 should be 65 km/sec; VHP for the Halley flights in 7/85 should be 69 km/sec.

This large correction in the value of VHP severely reduces the feasibility of ballistic flights to Halley's comet.